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OF THE

SMITHSONIAN INSTITUTION

VOLUME IV

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PREFACE.

The present Volume IV of the Annals of the Astrophysical Observatory covers a well-marked epoch in the work of the Astrophysical Observatory. Beginning immediately after the establishment of the real short-interval variability of the sun by the Algerian expeditions of 1911 and 1912, the period includes: The installation of the tower telescope on Mount Wilson in 1913 and the investigation therewith of the distribution of radiation over the solar disk and its variability; the preparation of automatic self-registering pyrheliometers, which, in 1914, were exposed from sounding balloons at an altitude of 25,000 meters with atmospheric pressure 3 centimeters, and giving there a maximum solar radiation intensity value of 1.84 calories per square centimeter, confirmed our results on the mean value of the solar constant; the investigations of Clayton on the correlation of the Mount Wilson observations of the solar variability with terrestrial meteorological conditions; the establishment by the Smithsonian private funds of a station at Calama, Chile, cooperating with Mount Wilson in the observation of solar variability; finally, the transfer, through the generosity of Mr. John A. Roebling, of the Mount Wilson work to Mount Harqua Hala, Arizona, and of the Calama work to Mount Montezuma, Chile, so that the investigation of solar variability will be continued at two stations 4,000 miles apart in cloudless regions of the Northern and Southern Hemispheres, as far as possible daily, until it is determined whether this observation is a worth-while meteorological element for forecasting and for the study of the problems of the atmosphere.

The work described in this volume owes a very large part of its value to the following members of the Observatory staff: Mr. A. Kramer, for 30 years instrument maker of the Astrophysical Observatory, who has constructed nearly all of the apparatus employed in the research; Miss F. A. Graves, for 12 years computer; Mrs. A. M. Bond, computer since 1918; Mr. A. F. Moore, director of the Hump Mountain and Chile stations from 1917 to 1920, and now director at Mount Harqua Hala, Arizona—Mr. Moore's versatility, efficiency and enthusiasm, and the sterling character of his work have all been abundantly demonstrated—and Mr. L. H. Abbot, assistant at Hump Mountain and Chile from 1917 to 1920, and now director of the Chile station.

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ANNALS OF THE ASTROPHYSICAL OBSERVATORY OF THE SMITHSONIAN INSTITUTION.

VOLUME IV.

INTRODUCTION.

PRINCIPAL INVESTIGATIONS.

Since the year 1902 we have carried on at the Astrophysical Observatory an investigation of the general question of the dependence of terrestrial affairs on radiation. There are two branches of this study. First, that relating to the incoming rays from the sun; second, that relating to the outgoing rays from the earth. Progress in both branches of the investigation requires suitable instruments. Volumes II and III of these Annals and numerous articles published in scientific periodicals and in the Smithsonian Miscellaneous Collections contain accounts of progress and descriptions of new forms of apparatus devised for the work.

In Volume II of the Annals, published in 1907, the first part gives an account of the work on solar radiation, the methods employed, the sources of error encountered, a description of the instruments in use at the time and the results of two years of investigation upon Mount Wilson and five years of investigation at Washington of the intensity of the solar radiation. In this investigation evidences of variability of the sun were indicated. This variability was of irregular interval and ranged apparently through a maximum of 10 per cent. The second part of the volume includes some measurements of the light of the sky, the reflection of clouds and a discussion of the balance of energy between the incoming rays from the sun and the outgoing rays from the earth, including an investigation of the reflecting and radiating power of the latter. Part 3 gives results of work in Washington on the distribution of radiation over the solar disk.

Volume III of the Annals, published in 1913, relates almost wholly to solar-radiation measurements. Improved methods and improved apparatus were described, including special apparatus for measuring the intensity of the solar radiation as a whole. The scale of measurement was definitely fixed so that the intensity of the solar rays could be expressed in calories per square centimeter per minute within an error thought to be less than half of 1 per cent. Results of observations at Mount Wilson from 1908 to 1912 were given and these still indicated the variability of the sun's rays outside our atmosphere, notwithstanding that improved methods of observing had diminished the probable inaccuracy of the work. What might before have appeared as possibly due to accidental error now seemed to be certainly caused either by changeability in the atmosphere or by actual changes in the sun. By means of simultaneous observations at Mount Wilson and Mount Whitney (the latter being the highest mountain in the United States) it appeared that the altitude of the observer, at least between sea level and 4,420 meters, played no part in altering the values obtained for the intensity of radiation of the sun outside the earth's atmosphere.

In order, however, to fully establish the solar character of the variations encountered, and to show that they existed independently of terrestrial influence, expeditions were made to the station at Bassour, Algeria, in the years 1911 and 1912. The results of observations for more than 50 days at both Bassour and Mount Wilson indicated that if high values were found at one station, high values would be found at the other and vice versa. Thus it made no difference in what quarter of the world the observer located himself, he found on the same days similar indications of solar variability, so that the conclusion is strongly confirmed that these variations exist in the sun itself and are not due to errors either of terrestrial atmospheric conditions or accidentally introduced by the instruments themselves.

The mean value of the solar constant of radiation, as determined by the work from 1902 to 1912, was found to be 1.933 [1] calories per square centimeter per minute. The variations of the sun were found to be not only of short periods of a few days but also to range over several per cent in the course of years, and to show correlation with the periodicity of sun-spot activity upon the sun's disk. During the year 1912, the ground-level observations at Mount Wilson and at Bassour showed the powerful influence of the great volcanic eruption at Mount Katmai in Alaska, which occurred on June 6, 1912. On June 19, the sky became slightly turbid in Bassour and a day or two later also at Mount Wilson. The milkiness increased rapidly and became very apparent, so that in July, and still more in August, a thick haze overspread the whole sky and cut off more than 20 per cent of the sun's direct radiation at noontime. Nevertheless the "solar-constant" values were not abnormal despite these extraordinary atmospheric conditions.

Values of the atmospheric transparency at Washington, Mount Wilson, Mount Whitney, and Bassour for average days, for very clear days, and for very hazy days, were tabulated. The form of the solar-energy curve outside the atmosphere was given as the result of many days of observation in many different years with a variety of instrumental equipments. Some of these observations were made at Washington, others at Mount Wilson, and still others at Mount Whitney. From these results estimates were formed of the probable temperatures prevailing in the sun.

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[1] A slight error occurred in publishing this value in Vol. III.

Small attention was given to the terrestrial side of the problems, but a summary was given of measurements of sky brightness at several stations.

Improved methods of reduction of the observations of 1907 made at Washington on the distribution of radiation over the sun's disk were described, and tabular values given for many wave lengths.

The Appendix of Volume III contains a bibliography of the principal papers published by the staff of the observatory and reprints of several of them.

In the light of eight years more of work which have been done since the publication of Volume III of the Annals there is very little to draw back or change from its results or conclusions. The standard scale of radiation which was established in 1910 still holds. The mean value of the solar constant is still believed to be close to 1.93 calories per square centimeter per minute. The sun is still regarded as a variable star, having short irregular variations of a few days or weeks and also longer-period variations of several years associated with the march of sun spots, prominences, and other solar phenomena. The transparency of the atmosphere is found to be represented by the same values as before, only varying from day to day according to the haziness encountered.

The method of reducing observations of the distribution of radiation over the sun's disk has not been changed, but great improvements in the apparatus for this investigation as now installed on Mount Wilson have been made.

In the present Volume IV of the Annals we continue the report of the solar work accomplished, describe improved solar instruments, also instruments adapted for measuring the radiation of the whole sky, and we fortify previous conclusions, first, as to the solar constant of radiation, and second, as to the variability of the sun. With reference to the former, we have devised, perfected, and successfully used a special automatically self-recording pyrheliometer capable of being exposed while attached to a sounding balloon. With reference to the latter we have found a correlation between the variations of the solar constant of radiation and certain variations of the distribution of light over the solar disk as seen in the telescopic image of the sun. The variations of distribution of the solar radiation are found to occur both from year to year and from day to day. Thus both the long-period and the short-period variations found in "solar-constant" work are confirmed by "solar-contrast" work. As a further confirmation of the short-period variation of the sun, several authors have published collateral investigations in which they have correlated our values of solar variation with variations of temperature, pressure, and magnetic conditions of the earth's surface. We refer particularly to Messrs. Arctowski, Bauer, Clayton, Helland-Hansen, and Nansen.

The effect of solar variation on terrestrial conditions is now so well established and so marked that it would be a very great pity if additional observatories in the most cloudless regions of the earth were not established for the purpose of investigating the solar variations. The Smithsonian Institution has done something in this direction. It supports in Chile a well equipped "solar-constant" station from the income of the Hodgkins fund. It is, however, very much to be desired that three or four other equally good stations employing similar apparatus and similar methods of observation should be established in the most cloudless regions of the earth well separated one from another.

On the terrestrial side of our investigations we have to report the work of Mr. Fowle on the transparency of long columns of atmospheric air, containing known quantities of humidity, to the radiations of great wave lengths such as the earth sends out. This investigation involves great difficulties owing to the fact that all the surroundings send out the same kind of radiations as those which are being investigated, so that it is as if an optical investigation was being made in which the observer was being showered with stray light from every direction. Secondly, the waves of very great wave length are transmitted by very few materials. Hitherto prisms of rock salt have been employed in such investigations, but this material practically ceases to be transparent for rays above the wave length of 20 μ, and a very interesting portion of the earth's radiation falls in the region of still greater wave lengths. A summary of Mr. Fowle's work will be given in a later chapter.

Some investigations have been made at Mount Wilson and at Washington by Mr. Aldrich on rays of more than 20 μ in wave length measured as a whole without regard to their spectrum distribution. These investigations will be given as a supplement to those of Mr. Fowle.

A very interesting piece of work was done by Dr. A. K. Ångström in the measurement of the nocturnal radiation at various altitudes. This work was supported by a grant from the Hodgkins fund of the Smithsonian Institution and was carried out by Dr. Ångström with the aid of several colleagues in southern California at stations ranging from sea level to 4,420 meters in elevation. The United States Weather Bureau collaborated in the work and sent up sounding balloons and captive balloons for the purpose of investigating the conditions of the upper air during the time when Dr. Ångström was making his measurements of nocturnal radiation.

Recently, Mr. Aldrich has employed the pyranometer, devised at this observatory, both in eclipse observations and in measurements of the reflecting power of clouds. An account of these investigations will be found in a later chapter.

GENERAL CONCLUSIONS THUS FAR REACHED.

1. The mean value of the intensity of solar radiation outside the atmosphere, measured over a sun-spot period, is about 1.94 calories per square centimeter per minute.

2. The sun is a variable star. Its variation is twofold. One variety is of long period associated with the variations of solar activity revealed in sun spots. The other variety is of short irregular periods of the order of days or weeks.

3. The variations of the sun decidedly affect the earth's weather. There is indeed great hope that a study of them will yield results of value for forecasting purposes. There is great need of additional observing stations in the most cloudless quarters of the world to make a more thorough study of the solar radiations for this purpose.

4. The temperature of the earth is profoundly dependent on the humidity of the air and to a less degree on the quantities of ozone and carbon dioxide which the air contains. A partial knowledge of these dependencies has been obtained, but further investigation is needed.

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Chapter I.

ANNALS.

The following selections from the annual reports of the Director give the progress of the work from the date of publication of Volume III of these Annals up to the present time:

FISCAL YEAR 1912–13.

VOLUME III OF THE ANNALS OF THE ASTROPHYSICAL OBSERVATORY.

The principal work of the year was the reduction of observations and the preparation for publication of Volume III of the Annals of the Astrophysical Observatory. (Quarto; pp. xi+241; tables, 70; inserted plates, 7; text figures, 32.) The manuscript was forwarded to the Public Printer on April 1, and the first completed copy of the book was received on July 3, 1913. About 1,400 copies have been distributed to libraries and individuals throughout the world.

In brief, the experiments described therein, which include the work of the observatory from 1907 to 1913, appear—

(*a*) To have established the scale of measurement of radiation to within 1 per cent;

(*b*) To have established the solar constant of radiation to within 1 per cent;

(*c*) To have shown by two independent methods that the sun's emission is not uniform but varies with an irregular periodicity of from 7 to 10 days on the average and with irregular amounts seldom if ever exceeding 10 per cent;

(*d*) To have shown that the sun also varies in connection with the sun-spot cycle. The solar emission appears to be increased at the earth's mean distance from the sun by about 0.07 of a calorie per square centimeter per minute for an increase of 100 Wolff sun-spot numbers.

(*e*) A marked effect of volcanic dust in the upper atmosphere on the radiation of the sun and on the temperature of the earth is indicated.

(*f*) Studies of the radiation of the sky, the effects of water vapor on the solar radiation, the distribution of radiation over the sun's disk, the probable temperature of the sun, and other subjects are included.

STUDIES OF THE TRANSMISSION OF LONG WAVE RAYS BY WATER VAPOR IN THE EARTH'S ATMOSPHERE.

Mr. Fowle's experiments on the transmission of radiation through long columns of air containing measured quantities of water vapor were temporarily discontinued owing to the need of completing the publication of Volume III of the Annals.

He, however, published a paper on the quantity of water vapor found above the Mount Wilson station.[1]

Toward the end of the fiscal year a vacuum bolometer was prepared for use in continuing the experiments on the transmission of very long wave rays through atmospheric water vapor. It is proposed to push this work in the immediate future.

THE CALIFORNIA EXPEDITION.

A grant of money from the Hodgkins fund having been made by the Institution to Dr. A. K. Ångström for observations of nocturnal radiation at different altitudes, several other lines of investigation were arranged to be included in connection with these researches. In the first place measurements were proposed on the total radiation from the sky by day. For this purpose and with the aid of a small grant from the Hodgkins fund Mr. Abbot devised and tested a special sky-radiation apparatus. This instrument comprises two blackened strips of metal which are exposed successively at the centers of two metal plates in such a way that the whole hemisphere of the sky is free to shine on the exposed blackened strip, but nothing can come from below the horizon toward the strips. Each strip is at the center of a hemispherical glass inclosure, which serves the purpose of preventing the exchange of rays of long wave lengths (associated with the temperature of such objects) between the blackened strip and the sky. Thus the apparatus serves to measure the quantity of radiation, originally coming from the sun, which has become diffusely scattered toward the horizontal surface by the molecules and dust particles found in the atmosphere.

Secondly, in order to determine the temperature and humidity prevailing above the stations occupied by Dr. Ångström's expedition, the Institution procured a large number of sounding balloons, and arrangements were made with the Weather Bureau for flying these balloons from Santa Catalina Island, carrying with each ascension self-recording apparatus of the Weather Bureau for measuring the temperature, pressure, and humidity of the air. Captive balloons belonging to the Weather Bureau were also arranged to be sent up at Lone Pine, California, and at Mount Whitney, California, while Dr. Ångström was occupying these two stations.

As certain writers have expressed doubt whether measurements of the solar constant of radiation made by Langley's method of high and low observations with the spectrobolometer really furnish the solar-radiation values as they would be found outside our atmosphere, it seemed desirable to check these results by observing at the highest possible altitudes the actual intensity of the solar radiation. For this purpose Mr. Abbot designed a form of pyrheliometer, similar in principle to the silver-disk pyrheliometer, but which is automatic and self-recording, and can be attached to a sounding balloon, and thus carried to very great heights. Five

[1] Astrophysical Journal, vol. 37, p. 359, 1913.

copies of this instrument were prepared at the observatory shops by Mr. Kramer and Mr. Abbot, and these were sent with the expedition to California. In anticipation it may be said that the five instruments were sent up on successive days, beginning July 30, 1913, and at the time of writing this report two of them have been recovered. Each of the two had a readable record of the ascension.

The results are subject to later recomputation, but they indicate at least that our solar-constant work of 1902–1912 by high and low sun observations on homogeneous rays, according to Langley's methods, gives results of the same order of magnitude as those obtained by direct pyrheliometric observations at extremely high altitudes.

PERSONNEL.

No change has occurred in the staff of the observatory, except that Miss F. E. Frisby completed her temporary service as computer on June 30, 1913, and Dr. A. K. Ångström served as temporary bolometric assistant in Algeria from July 1, 1912, to September 30, 1912.

FISCAL YEAR 1913–14.

AT WASHINGTON.

Observations.—Mr. Fowle has continued the difficult research on the transmission through moist air of radiations of great wave length, such, for instance, as those bodies which at the temperature of the earth emit most freely. He uses a very powerful lamp made up of a large number of Nernst electric glowers, and examines by the aid of the spectrobolometer the energy spectrum of the rays emitted by this lamp, first directly, and then, after the rays have traversed twice or four times a tube 200 feet long, containing air of measured humidity. During the past year Mr. Fowle has been dealing principally with rays of the very longest wave-lengths of the terrestrial energy spectrum which moist air transmits. He has reached a wave length of about 18 microns, which is about twenty-five times the longest wave length visible to the eye, and about three and one-half times the wave length of the solar rays investigated by this observatory in the years 1890 to 1900.

A great number of difficulties are met with. In the first place, great sensitiveness of the bolometer is required, owing to the feebleness of these rays. Attempts to use a vacuum bolometer have consumed much time, but not yet with entire success. Full success in this seems now probable. In the second place there is great difficulty in determining the amount of radiation lost in the optical train required to reflect the beam to and fro through the long tube. A principal difficulty in this matter arises from the fact that the lamp and its surroundings are unequally hot at different parts, for this has led to different degrees of loss at different wave lengths. This last source of error is so obscure that it escaped our attention for a long time and has required the observations to be repeated after results worthy of publication had, as it was thought, been reached. These and a host of other difficulties have delayed the research, but great hope is now felt that satisfactory results will be ready for publication in another year.

Computations.—The reductions of Mount Wilson and Washington observations take a large part of the time of Mr. Fowle and Mr. Aldrich, as well as the entire time of Miss Graves and a portion of that of Mr. Carrington. This work is nearly up to date.

Mr. Fowle has continued the study of the effect of terrestrial water vapor on the Mount Wilson solar observations and has published several valuable papers upon it. An interesting result is, that after determining and correcting for the effect of atmospheric water vapor on the transmission of solar rays, the coefficients of atmospheric transparency determined at Mount Wilson, when combined with the barometric pressure after the manner indicated by Lord Rayleigh's theory of gaseous scattering of light, yield the value 2.70 billion billion as the number of molecules at standard pressure and temperature in a cubic centimeter of gas. Prof. Millikan, by a wholly independent kind of reasoning, has derived from electrical experiments the value 2.705 billion billion. The close agreement found is a strong confirmation of the accuracy of our determinations of atmospheric transparency, and accordingly tends to increase confidence in our determination of the solar constant of radiation.

PREPARATION OF APPARATUS.

Sky radiation instruments.—The director and Mr. Aldrich have devoted much time to the design and testing of apparatus for measuring the scattered radiation of the sky by day. What is desired is an instrument exposing horizontally an absorber of radiation in such a manner that the rays of the entire visible hemisphere of the sky would be received upon it, all rays not of solar origin would be excluded by a suitable screen, and the total energy of the scattered sky radiation originally emitted by the sun would be measured accurately. This is a more difficult problem than the measurement of the direct solar radiation, and it is unlikely that quite as high precision can be attained with the sky radiation instrument as with the pyrheliometers used for measuring direct solar radiation. From experiments with several instruments of the kind which have been constructed in the observatory shop by Mr. Kramer and tested by Messrs. Abbot and Aldrich it now seems probable that the sources of error can be so far eliminated that sky radiation measurements accurate to about 2 per cent will be made. An instrument embodying what are thought to be the final improvements of design is now under construction, and it is hoped it will be used a great deal in the coming year.

Balloon pyrheliometers.—Still more time has been devoted by Messrs. Abbot, Aldrich, and Kramer to the reconstruction and testing of balloon pyrheliometers. Mention was made in last year's report of the proposed measurements of solar radiation by apparatus attached to sounding balloons and raised to great elevations.

As stated below, the first trials in August, 1913, while unexpectedly successful in many ways, did not enable us to obtain measurements above the elevation of about 14,000 meters, or 45,000 feet. At this elevation the mercury froze in the thermometers. Also, the clockwork proved not sufficiently accurate for best results. Still the results obtained were so promising that it was thought well to repeat the experiments.

Accordingly the five balloon pyrheliometers were reconstructed. Excellent French clocks were substituted for those used in 1913, and many improvements of the instruments were introduced. Two devices were employed to prevent the freezing of the mercury in the thermometer. In some instruments water jackets, having numerous interior copper bars to act as heat conductors, were arranged. In these it was hoped to make available the latent heat of freezing of the water and thus to prevent the surroundings of the pyrheliometric apparatus from descending far below the freezing point of water. In other instruments electrical temperature regulators were provided. Many experiments were tried to obtain a constant, powerful, and very light electric battery for this purpose. At length a modification of the Roberts cell was designed, in which individual cells weighing 20 grams ($\frac{3}{4}$ ounce) would furnish a constant potential of 1.3 volts and yield a nearly constant current of about 0.5 ampere for nearly two hours. The internal resistance of the cells was only about 0.3 ohm. Barometric elements were made to record on the same drum that recorded radiation. One instrument was constructed to be sent up at night, so as to show if any unexpected phenomena occurred when the instruments were being raised, apart from those due to the sun. Many tests of the instruments were made at different temperatures and pressures, and while immersed in descending air currents comparable to those anticipated to attend the flights.

Silver-disk pyrheliometers.—As in former years, a number of silver-disk pyrheliometers were standardized at the observatory and sent out by the Institution to several foreign Government observatories.

IN THE FIELD.

Mount Wilson Expedition of 1913.

Mr. Aldrich went to Mount Wilson early in July, 1913, and carried on there solar-constant measurements until September, when he was joined and then relieved by Mr. Abbot, who continued the observations until November. An expedition at the charge of the private funds of the Smithsonian, and under the direction of Dr. A. K. Ångström, was in California during July and August for the purpose of measuring nocturnal radiation at different altitudes, ranging from below sea level to the summit of Mount Whitney, 4,420 meters (14,502 feet). Mr. Aldrich cooperated as far as possible with this expedition.

Balloon pyrheliometry.—At the same time a cooperating expedition from the United States Weather Bureau made ascents of captive and free balloons in order to determine the temperature, pressure, and humidity at great elevations, for use in reducing Dr. Ångström's observations. Advantage was taken of the opportunity to send up special pyrheliometers for measuring solar radiation at great altitudes. These experiments, which weıe made jointly by Mr. Aldrich and Mr. Sherry of the Weather Bureau, were referred to by anticipation in last year's report. Five balloon pyrheliometers were sent up from Santa Catalina Island. All were recovered, with readable records. One instrument unfortunately lay in a field about six weeks before recovery, and parts of its record referring to the higher elevations were obliterated, but it yielded the best results of any up to about 8,000 meters. Two of the instruments unfortunately were shaded by cirrus clouds until after the mercury froze in their thermometers. The highest elevation at which a radiation record was obtained was about 14,000 meters, or nearly 45,000 feet. As stated in last year's report no results indicating that values of solar radiation exceeding ouı solar-constant value (1.93 calories) are obtainable by pyrheliometric measurements at any elevation, however high, appear from these balloon pyrheliometer experiments. In view of the proposed repetition of the experiments with improved apparatus no further statement of these preliminary results is necessary here.

The tower-telescope work.—As stated in former reports, investigations were carried on at Washington during the years 1904 to 1907 to determine the distribution of the sun's radiation along the diameter of the solar disk. It was shown by this work, in accord with results of earlier observers, that the edge of the solar disk is much less bright than the center, and that this contrast of brightness is very great for violet and ultra-violet rays, but diminishes steadily with increasing wave lengths, and becomes very slight for red and especially for infra-red rays. The measurements were continued at Washington on all suitable days in the hope that some fluctuation of this contrast of brightness between the edge and center of the solar disk would be disclosed. It seemed probable that there might be such fluctuations associated with the irregular variability of the total solar radiation. It proved, however, that such fluctuations, if existing, were of so small an order of magnitude that it was not certain whether they were really shown by the observations at Washington, hampered as these were by variable transparency of the air.

When the observing station was erected on Mount Wilson in 1908 provision was made for a tower telescope designed to continue this research. When in 1911 and 1912 the Algerian expeditions confirmed the sun's variability, added interest was felt in the proposed experiments. Accordingly, the tower, 50 feet in height, was completed in 1912. Not sufficient funds were available to equip the tower telescope, but Director Hale, of the Mount Wilson Solar Observatory, kindly loaned considerable apparatus, and with this and some apparatus which remained from eclipse expeditions, and by using anything available, as, for instance, a trunk of a tree for a mirror support at the top of the tower, Messrs. Abbot and Aldrich succeeded in getting arranged on the tower a reflecting telescope of 12 inches aperture and 75 feet focus, all ready for observations by September 9, 1913. Then and thereafter solar-constant measurements were supplemented by determinations of the distribution of radiation along the sun's diameter on each day of observation. These determinations are made in seven different wave lengths on each day, ranging from 0.38μ in the ultra violet to 1.1μ in the infra-red. Fortunately, the definition of the tower telescope proves to be very good. There is slight change of focus during the several hours of observing, and the "seeing" seems not to deteriorate much up to 10 o'clock a. m., at which time the observations are generally concluded.

About 45 days of simultaneous observations of the "solar constant" and of the distribution of radiation over the sun's disk were secured in 1913. The results appear to indicate a variability in both phenomena and a distinct correlation of the two in point of time. It is indicated that when in course of its short-period irregular variation the solar radiation increases, there occurs simultaneously a diminution of the contrast between the edge and center of the sun's disk. A change of brightness of about 1.5 per cent was found to occur at 95 per cent out on the solar radius accompanying a change of 6 per cent in the solar radiation. On comparing the mean of all results obtained in 1913 with the mean of all obtained in Washington in 1906–7, it appears that there was distinctly less contrast of brightness between the edge and center of the sun's disk in 1913 than in 1907. We have reason, however, to believe that there was distinctly a greater total solar radiation in 1907 than in 1913. This result, compared with the result stated above, indicates a difference of character between the long-period fluctuations of the sun and its short-period irregular fluctuations. The changes of contrast found, however, agree in this, that whether from day to day in 1913, or as between 1913 and 1907, the violet or shorter wave lengths change in contrast more than the red or longer wave lengths.

Mount Wilson Expedition of 1914.

Mr. Abbot continued the Mount Wilson work, beginning in May, 1914. Many improvements were made in the tower telescope, leading to improved definition and stability of the image of the sun. Improved methods of observing were introduced also.

BALLOON PYRHELIOMETRY.

Mr. Aldrich, in cooperation with the United States Weather Bureau observers, under personal direction of Dr. Blair, arranged to repeat the balloon pyrheliometer observations, and this time at Omaha. Ascensions were not made until after July 1, 1914, but it may be said in anticipation that two ascensions by day and one by night were made. All three instruments were recovered. No unexpected phenomena were disclosed by the night record. One day record appears to be excellent. Fortunately the instrument which recorded it came back uninjured, and further tests and calibrations with it are intended. The instrument reached a very great height, and recorded radiation successfully until after it began to descend. Preliminary reductions show that the values recorded fall below our adopted value of the solar constant of radiation.

FISCAL YEAR 1914–15.

AT WASHINGTON.

Observations were maae for the testing of pyrheliometers. As in former years several silver-disk pyrheliometers were prepared and sent abroad by the Institution after standardization at the Astrophysical Observatory.

Several automatic recording pyrheliometers were raised to great heights in sounding-balloon experiments at Omaha early in July, 1914. These instruments were all recovered, and the one which made the most successful flight was received back entirely uninjured. A great many experiments were made with it at Washington to investigate certain peculiarities of its record, and to more thoroughly standardize its pyrheliometric and barometric elements. These experiments consumed much time of the director and Mr. Aldrich. The results reached from these balloon pyrheliometer records will be summarized below.

Further experiments were made with sky-radiation apparatus.

As in former years the major portion of the time of Mr. Fowle and Miss Graves, and a considerable part of that of Mr. Aldrich and Mr. Carrington, has been used in measuring and reducing the Mount Wilson bolographic data. This work is heavier than formerly, as it now includes the tower-telescope observations on the distribution of brightness along the sun's diameter. These are now made at seven different wave lengths of the spectrum on each day that solar-constant measurements are secured. Owing to the demands of the Mount Wilson work, Mr. Fowle has devoted but little time to his research on the transmission of long-wave rays in air containing water vapor.

The instrument maker, Mr. Kramer, was occupied mainly on the construction of sky-radiation apparatus, and on many improvements for the Mount Wilson tower telescope.

AT MOUNT WILSON.

Observations by Messrs. Abbot and Aldrich were continued at Mount Wilson from July to about November 1, 1914, and were begun again about June 1, 1915. As in former years measurements of solar radiation were made on every favorable day, with the purpose of following the course of the solar variation. On each day of observation the distribution of brightness along the diameter of the solar image of the tower telescope was also observed at seven different wave lengths.

AT OMAHA.

As stated in last year's report, Mr. Aldrich, in cooperation with Dr. Blair and other representatives of the United States Weather Bureau, made sounding-balloon experiments at Omaha early in July, 1914. Three flights with automatic recording pyrheliometers were made on July 1, 9, and 11, respectively. The first was made at night, with electric lamps for recording, as a test of certain anticipated sources of error. In the second flight the instrument was much damaged when landing and remained a great while undiscovered, so that the record was quite spoiled. Apparently, too, the clockwork had stopped before reaching a very great elevation. The third flight was highly successful.

RESULTS OF BALLOON PYRHELIOMETRY.

A complete account of the balloon pyrheliometers, the circumstances of the flights, and the results obtained have been published in a paper by Messrs. Abbot, Fowle, and Aldrich, entitled, "New Evidence on the Intensity of Solar Radiation Outside the Atmosphere" (Smithsonian Miscellaneous Collections, vol. 65, No. 4, 1915). The following is a summary of the principal results:

In the flight of July 11, 1914, the balloons reached an elevation of approximately 25,000 meters, or 81,000 feet. The pressure of the air remaining above the instrument was approximately 3 centimeters, or 1.25 inches of mercury, about one twenty-fifth of the barometric pressure at sea level. Seven readable measurements of solar radiation were recorded at various levels. Of these the three near highest elevation were the best. Their mean gives a value of 1.84 calories per square centimeter per minute, as the intensity of solar radiation at mean solar distance, at noon on July 11, at the altitude of about 22,000 meters, or 72,000 feet. It appears reasonable to add about 2 per cent for the quantity of solar radiation absorbed and scattered by the air above the instrument. This gives 1.88 calories as a value of the solar radiation outside the atmosphere, on this day, according to the balloon pyrheliometry. Unfortunately no solar-radiation measurements were secured on Mount Wilson on July 11, but the result falls well within the range of values for the solar constant of radiation which have been obtained by the bolometric method at various stations, and compares well with the mean of these values, 1.93 calories.

UNIFORMITY OF ATMOSPHERIC TRANSMISSION AT MOUNT WILSON.

In solar-constant measurements on Mount Wilson the atmospheric transmission for vertical rays is determined in the following manner for numerous spectrum wave lengths:

Spectrobolographic observations are made at different zenith distances of the sun, usually between 75° and 30°. Between these limits the length of the path of the rays within the atmosphere is proportional to the secant of the zenith distance. Knowing the length of path and the intensity of the transmitted rays, the coefficient of transmission for any ray is readily computed. In this determination it is assumed that the atmosphere remains unchanged in transparency during the whole period of observation. Several critics have objected against the Mount Wilson measurements that a progressive decrease of transparency occurs during the morning hours, and especially during the period ordinarily used in our observations, so that our estimates of atmospheric transmission are in their view too high, and our solar-constant values too low in consequence. It has been suggested by one critic that the period during which the zenith distance of the sun changes from 85° to 75° would be more suitable for the work.

To test this matter, observations were begun at sunrise on September 20 and 21, 1914, and continued until 10 o'clock, the usual closing time. These days were exceptionally clear and very dry, and seemed well suited to give excellent solar-constant values. The conditions of experiment, discussion of observations, and results are given in full in the paper by Abbot, Fowle, and Aldrich above cited. The principal results are these: No considerable difference in transmission coefficients appeared whether these were based on the whole morning's observations, on the range of air masses usually employed, or on the range recommended by the critic above mentioned. Six solar-constant values were derived for the two days, based on these three different treatments of the data. All six values fall between 1.90 and 1.95 calories per square centimeter per minute, in good agreement with values obtained as usual on other days. The experiments confirm the view that the atmospheric transparency above Mount Wilson is sufficiently uniform for the purposes of solar-constant investigations.

LONG-PERIOD VARIATION OF THE SUN.

In the year 1913 the solar activity, as judged by the prevalence of sun spots, was less than at any time for about a century. The mean of all solar-constant values obtained at Mount Wilson from July to October, 1913, inclusive, was 1.885 calories per square centimeter per minute. This value falls 2.5 per cent below the mean value for the years 1905 to 1912, which was 1.933 calories.

Beginning September 9, 1913, observations of the distribution of radiation along the diameter of the solar disk were secured on about 45 days of September, October, and November. These showed that the increase (or contrast) of brightness of the center of the sun's disk over that which prevails near the edge was less than that which was found from Washington observations of the years 1905 to 1907.

In the year 1914 the solar activity became distinctly greater than in 1913. The number of spots, to be sure, was not great, but other phenomena joined in showing that the period of maximum sun spots was about to come. The mean of all solar-constant values obtained at Mount Wilson from June to October, inclusive, was 1.950 calories. This value is 3.5 per cent above that of 1913 and 1 per cent above the mean for former years. Indications are that the value for 1915 will also fall very high.

The contrast of brightness between the center and edges of the solar disk was greater in 1914 than in 1913, and, in fact, almost as great as was found from Washington work of 1905 to 1907.

These facts confirm the result derived from earlier observations, namely, the solar emission of radiation varies along with the solar activity as revealed by sun spots and other phenomena. Higher values of solar radiation prevail at times of greater solar activity, as expressed by sun spots. The connection does not, however, appear to be a strictly numerical one between solar radiation and sun spot numbers. In the return of solar activity presaged in 1914 the solar radiation rose almost to its maximum value before the number of sun spots had greatly increased. Associated with these changes, greater contrast of brightness between the center and edges of the solar disk prevails when the solar activity is greater.

SHORT-PERIOD VARIATION OF THE SUN.

In the year 1913, as in former years, considerable fluctuations of the solar-constant values occurred from day to day. The values found ranged over nearly 10 per cent between the extreme limits 1.81 and 1.99 calories, but seldom more than 3 per cent in any 10-day interval. The periods of fluctuation were irregular, as heretofore. Associated with these fluctuations, though perhaps not strictly connected numerically, the contrast of brightness between center and edges of the solar disk also varied. Curiously enough, however, the correlation between solar-constant values and contrast values proves to be of opposite sign for these short irregular fluctuations to that which attends the long-period changes which are associated with the general solar activity. In other words, in the progress of the sun-spot cycle *high* solar-constant values and *increased* contrast between center and edges of the solar disk are associated together with numerous sun spots, but for the *short* irregular period fluctuations of solar radiation, *higher* solar-constant values are associated with *diminished* contrast of brightness along the diameter of the solar disk. The year 1914 was singularly free from large fluctuations of solar radiation. The extreme range of solar-constant values was only 4 per cent between limits 1.91 and 1.99 calories. Accordingly the year was not very favorable for testing the relation just described. Nevertheless, the results tend to confirm rather than disprove the conclusion reached that for short, irregular fluctuations of the solar radiation high values are associated with less contrast of brightness between the center and edges of the sun.

The somewhat paradoxical conclusions above stated seem capable of explanation as follows: Associated with the great increase of solar activity attending the maximum of the sun-spot cycle, increased convection is continually bringing fresh hot material to the sun's surface, so that the effective solar temperature is then higher, and greater emission of radiation prevails. At such a time the contrast, which would be zero if the solar temperature were zero, is naturally also increased. As for the quick, irregular fluctuations, it must be supposed that the sun's outer envelope hinders somewhat the passage of radiation from within outward. This hindrance is greater at the edges of the sun's disk, where the path of the rays in the line of sight is oblique, than it is at the center of the sun's disk. Suppose now that the obstructive property of these layers varies from day to day. When their transparency is increased the solar radiation must *increase;* but as the effect will be most conspicuous at the edge of the solar disk, where the path of the rays is longest, the *contrast* of brightness between center and limb must thereby *decrease.*

Two kinds of causes may, therefore, contribute to the sun's variability. The one, a change of effective temperature attending the general march of solar activity, may cause the variability of long period. The other, a change of opacity of the outer solar layers, may cause the variability of short irregular period.

FISCAL YEAR 1915-16.

AT WASHINGTON.

Some years ago the Institution lent the Harvard College Observatory a silver-disk pyrheliometer for use at Arequipa, Peru. By request of Prof. Pickering the observations which had accumulated since August, 1912, were reduced at the Astrophysical Observatory and published by the Smithsonian Institution during the past year.[2] Owing to the high altitude of Arequipa the variations of solar radiation observed at a fixed zenith distance of the sun (as, for instance, that whose secant is 1.2) were found to be almost wholly governed by three things—the atmospheric humidity, the distance of the sun, and the variations of the sun's emission. Hence from measurements of the humidity by the psychrometer it was possible to compute from the observed radiation the probable intensity of the solar radiation outside the atmosphere for each day. These empirical solar-constant values from Arequipa observations confirm the variations of the sun observed at Mount Wilson by the complete spectrobolometric process. Indeed, it appears that if eight or ten well-separated stations at high altitudes should be equipped with the pyrheliometer and psychrometer their combined results might well be expected to determine closely enough the sun's variations. A most interesting feature of Arequipa observations is that there is nothing anomalous about the observations of 1912 to suggest that the volcanic eruption of Mount Katmai (of June 6, 1912), which produced a great deal of dust all over the northern hemisphere, produced any turbidity of the atmosphere whatever south of the Equator.

[2] Arequipa Pyrheliometry, Smithsonian Miscellaneous Collections, vol. 65, no. 9, 1916.

Results of Mount Wilson solar-constant observations have been furnished in advance of publication to Dr. Bauer of the Carnegie Institution for comparison with magnetic data. He finds a close correlation between certain fluctuations of the earth's magnetic field and the variations of solar radiation.

The tower-telescope observations of the distribution of radiation along the diameter of the sun's disk, made at Mount Wilson in 1913 and 1914, having been fully reduced, a preliminary publication of them has been made by the Smithsonian Institution.[3] These results show distinctly that the average distribution of solar radiation over the solar disk varies from year to year. Greater contrast of brightness between the center and limb of the sun prevailed in 1907 and 1914 than in 1913. The change is greater for short wave lengths than for longer ones. Changes also occur from day to day. Both of these kinds of changes are found correlated with changes of the solar constant of radiation, but in opposite senses. High values of the solar radiation attend periods of greater solar activity and are associated with increased contrast of brightness between the center and edge of the solar disk. For short-period fluctuations of solar radiation, however, low values of solar radiation are associated with increased contrast. It seems reasonable to suppose that the first kind of phenomena is caused by increased convection in the sun, bringing fresh radiating surfaces forward more rapidly, thus increasing the effective solar temperature. The second kind of phenomena may be caused by temporary increases of the turbidity of the outer solar envelopes, restricting the solar emission especially at the limb.

Mount Wilson observations of 1915, including both the solar-constant work and the tower work, have been almost all reduced.

Mr. Fowle has continued at intervals between other work the reduction of his numerous observations of the transmission of rays of great wave length through long columns of air of known humidity. Many sources of error have required to be considered and eliminated, and the reading and reduction of the curves of observation was extremely tedious. The results are at length reaching such a stage that it can be seen that they fall into excellent agreement and will be of high interest in connection with studies of the earth's temperature as dependent on its radiation outward toward space. In fact, the results of Mr. Fowle's work are expected to be ready for publication within a short time.

For some years we have endeavored to design and construct an instrument capable of measuring accurately the intensity of sky light by day and of radiation outward toward the whole sky by night. At last success seems to be reached in an instrument devised by Messrs. Abbot and Aldrich and constructed by Mr. Kramer. The instrument is called the pyranometer, from the Greek words πῦρ,

[3] On the Distribution of Radiation over the Sun's Disk and New Evidences of the Solar Variability. Smithsonian Miscellaneous Collections, vol. 66, no. 5, May, 1916.

fire, ἀνά, up, μέτρον, a measure; thus designating an instrument adapted to measure heat coming from or going to space above. The pyranometer is somewhat after the principle of the Ångström pyrheliometer, in that the intensity of radiation is measured by electrical compensating currents, whose strength is adjusted with reference to the indications of a delicate thermocouple. A full account of the instrument has been published by the Smithsonian Institution,[4] including the tests which have been made to determine its accuracy by comparisons in solar measurements with the pyrheliometer. Complete accord between the two instruments is found at all altitudes of the sun when due regard is paid to the fact that the pyranometer presents a horizontal surface. The pyranometer seems to be suitable for botanical investigations, for it is capable of measuring the radiation even in deep shade, as in forests and greenhouses, as well as in full sun. In short, it can measure radiation in all situations where plants are accustomed to grow, except under water.

The consideration of the pyranometer has led us to undertake the determination of the constant ordinarily called "sigma" of Stefan's formula of radiation, according to which the emission of a perfect radiator per square centimeter per second is equal to the fourth power of the absolute temperature multiplied by "sigma." In recent years a good deal of disagreement has arisen as to the value of "sigma." We require to use it for certain tests of the pyranometer and have devised a new method which seems very free from error for making its determination. The apparatus has been constructed and is now set up practically ready for use.

AT MOUNT WILSON.

Messrs. Abbot and Aldrich continued observations at Mount Wilson of the solar constant of radiation from July 1 to October 22, 1915, and renewed the expedition early in June, 1916. Besides conducting solar-constant observations and determinations of the distribution of light over the sun's disk in seven different wave lengths on each favorable day, comparisons of the pyrheliometers used ordinarily on Mount Wilson were made in both 1915 and 1916 with standard water-flow pyrheliometer No. 3. The comparisons showed no change to have occurred in the sensitiveness of secondary pyrheliometers Nos. IV and VII, on whose readings rest the solar-constant determinations made at Mount Wilson since 1906.

A good deal of attention was also given to the installation and trial of a solar cooking apparatus comprising ovens heated by oil under gravity circulation maintained by heat collected by a concave cylindric mirror of about 100 square feet surface. The apparatus seems highly promising, but owing to a couple of defects was not in satisfactory operation until after the close of the period covered by this report.

[4] The Pyranometer—an Instrument for Measuring Sky Radiation. Smithsonian Miscellaneous Collections, vol. 66, no. 7, May, 1916.

PROPOSED SOLAR-CONSTANT EXPEDITION.

On recommendation of the writer an allotment was made from the Hodgkins fund of the Smithsonian Institution for the purpose of duplicating the solar-constant work of Mount Wilson at the most favorable station on the earth. The expedition is being prepared and will go forward, probably to South America, in the summer of 1917. It is intended to continue solar-constant determinations by the spectro-bolometric method on every favorable day in every month of the year for several years at both Mount Wilson and the station in South America, with a view to determining the dependence of the earth's climatic conditions on the sun's variations of radiation.

FISCAL YEAR 1916-17.

AT WASHINGTON.

Three copies of the pyranometer, our new instrument for measuring sky radiation, have been prepared by the Institution, respectively, for the United States Weather Bureau, the University of Wisconsin, and for the proposed expedition to South America mentioned in my report for 1916. These instruments were finished and standardized by Mr. Aldrich. The tests made led to long investigations and improvements, which greatly increased the sensitiveness of the pyranometer. All three instruments are now in use and, so far as known, with satisfaction.

Two silver-disk pyrheliometers were standardized for the proposed South American expedition.

Considerable work was done on the apparatus mentioned last year, designed to measure the constant of the fourth-power radiation formula. Owing to trouble found in maintaining a vacuum in the apparatus no actual determinations were made.

Much attention was devoted to the preparation of the equipment of a solar-constant expedition for South America. The purpose of the expedition, as stated last year, is by cooperation with Mount Wilson to secure daily values as far as possible throughout the year for several years, and thus to investigate the influence of solar variation on terrestrial temperature. Many improved devices were invented and constructed for the expedition. Among them is a new vacuum bolometer of very high sensitiveness and in every way exemplary behavior. This instrument is constructed in such a way as to be sealed off when highly exhausted, like an X-ray tube. Having no cocks or windows it requires no further attention to maintain a vacuum indefinitely. The construction of the sensitive strips follows the indications of mathematical analysis covering the whole theory of the bolometer, so that a maximum sensitiveness is obtained. A similar instrument was prepared also for Mount Wilson work. The high sensitiveness of the new bolometer is indicated by the statement that when used with the same spectroscope and galvanometer employed in our Algerian expedition of 1912 more than tenfold deflections on the solar spectrum were observed with similar conditions.

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Another new instrument is a special machine designed to aid in reducing spectrobolometry, in solar-constant work. Heretofore we have plotted, on large cross-section paper, logarithms of observed radiation against the air masses traversed by the solar beam. Nearly forty such plots, each of six points, are required to represent a morning's spectrobolometry. The plotted points fall in approximately straight lines, whose projection to the zero of air mass yields logarithms of intensities as they would be observed outside our atmosphere. The inclinations of the representative straight lines give the logarithms of the atmospheric transmission coefficients. What I desire to point out is that the process requires taking out about 300 logarithms, besides plotting and extrapolating.

In the new instrument six 16-inch slide rules are arranged to be set at chosen places and at right angles to a horizontal linear scale of air masses. The observations are set up by reading the crossline of the sliders against the central movable slide-rule scales, these latter being set with respect to the fixed scales on the sides so as to apply a small correction for sensitiveness of the bolometric apparatus. A stretched wire is then adjusted to fit the six points as thus plotted. On another slide rule fixed at zero air mass one reading of the crossing point of the wire over the fixed scale gives the intensity as it would be outside the atnosphere, and a second reading on the movable scale gives the atmospheric transmission coefficient. No logarithms or computing are required.

The equipment of the expedition was all boxed ready for shipment to South America when circumstances connected with the war with Germany led to a postponement. Under these circumstances it was deemed best to send the expedition to Hump Mountain in North Carolina, a station at 4,800 feet elevation, where it is now located. This location was chosen with a view to its being at a great distance from Mount Wilson, in a region where Weather Bureau observers reported uncommonly little cloudiness, and easily accessible from the railroad and from Washington.

The expedition with over 3 tons of equipment went forward in May, 1917. It is in charge of Mr. A. F. Moore, who is assisted by Mr. L. H. Abbot. Two small frame buildings were erected for the observing and living quarters. The apparatus was set up and adjusted by Messrs. C. G. Abbot, L. B. Aldrich, and A. F. Moore, and gotten ready for observing about June 15. Unfortunately the most cloudy and rainy summer in the recollection of old residents had been experienced up to August 1. Otherwise, everything is highly favorable to excellent solar-constant work. If war conditions warrant, the Institution still hopes to send the expedition to South America later, where a station is selected at which 300 cloudless forenoons for observing per year are to be expected.

Before leaving this subject I desire to call attention to the remarkable paper by Mr. H. Helm Clayton (Smithsonian Miscellaneous Collections, vol. 68, no. 3) on the "Effect of Short Period Variations of Solar Radiation on the Earth's Atmosphere." Mr. Clayton shows by the mathematical method of correlations, free from all influence of personal judgment, that variations of solar radiation observed by us at Mount Wilson in 1913 and 1914 were reflected in variations of terrestrial temperatures all over the world. The correlations were positive in and near the Tropics, negative in temperate zones, and positive near the poles. A lag of from 1 to 5 days occurred, the lag being less for tropical zones. The barometric pressure also appeared to join in the correlations. By an ingenious application of his method Mr. Clayton shows that the short interval fluctuations of solar radiation are not altogether without periodicity, for the changes tend to repeat themselves after 12 and 22 days, respectively. The same tendency is found in the temperature records of Buenos Aires. We are now engaged in testing this conclusion by computations for other years.

Computations of Mount Wilson solar observations went on in the hands of Miss Graves as usual at Washington, and the computing is practically up to date.

Mr. Fowle's research on the effect of water vapor and carbon dioxide of the atmosphere to absorb long-wave rays, such as the earth sends out, is now ready for publication. Many of the best observations were made by him during the past year. Some observations made in February, 1917, at a time when the humidity of the atmosphere was very small, proved of special value. Opportunity was taken of using some of the apparatus prepared for the South American expedition to aid in making bolographic observations on the solar spectrum at very great wave lengths, reaching to 17 microns. By means of the spectrobolometer prepared for South America it was possible to determine accurately the quantities of water vapor in the path of the solar beam.

Certain conclusions stated in Volume II of the Annals of the Astrophysical Observatory may now be corrected to correspond with the new information. We stated:

> We can by no means admit that the radiation from the solid and liquid surface of the earth passes unhindered to space. * * * The clouds, whose average presence includes 52 per cent of the time, * * * are even more efficient screens to the radiation of the earth than they are to the radiation of the sun, so during 52 per cent of the time we may regard the radiation of the solid and liquid earth to space as zero. During the remainder of the time water vapor presents almost as effective a screen. * * * From the combined work of Rubens and Aschkinass, Langley, Keeler and Very, and Nichols, we * * * conclude that a tenth part of the average amount of water vapor in the vertical column of atmosphere above sea level is enough to absorb more than half of the radiation of the earth to space, and it is highly probable that, considering the greater air mass attending the oblique passage of many of the rays to space, nine-tenths of the radiation of the solid and liquid surface of the earth is absorbed by the water vapor of the atmosphere even on clear days. On cloudy days none is transmitted, so that the average escape of radiation from the earth's surface to space probably does not exceed 5 per cent.

Some writers have attributed a large share of the absorption of the atmosphere to the carbonic-acid gas which it contains, but * * * in atmospheric conditions the absorption of carbonic-acid gas in the spectrum of the earth appears to be confined to two bands extending from wave lengths 3.6 to 5.4μ, and from 13.0 to 16.0μ, respectively. In these bands its absorption is nearly total from 4.0 to 4.8μ and from 14.0 to 15.6μ even when carbonic-acid gas is present in much less quantities than the atmosphere contains. * * * In the absence of water vapor the total absorption possible by carbonic-acid gas would be 14 per cent. In all the lower regions of the atmosphere, however, water vapor is present in such quantities as almost completely to extinguish the radiation of the earth's surface in these two special regions. * * * It therefore does not appear possible that the presence or absence, or increase or decrease, of the carbonic-acid contents of the air are likely to appreciably influence the temperature of the earth's surface.

It seems certain, in view of what has been said, that the earth's solid and liquid surfaces, and the lower parts of the atmosphere, contribute directly almost nothing to the amount of radiation which the earth as a planet sends to space. The earth's surface and the lower atmosphere, of course, exchange radiation together, and by this process and by convection the heat of these regions ascends toward space. But convection grows less and less as the air becomes rarer, and must at length cease to be an appreciable factor. It is the water vapor and carbonic-acid gas far above the earth's surface, where the absorption of the rays by the water vapor and carbonic-acid gas lying still higher becomes small, that form the true radiating surface of the earth considered as a planet. * * * With the scanty material at hand, and in consideration of the distribution of water vapor in the free air, it seems safe to put the effective position of the radiating surface at fully 4,000 meters above sea level * * * at a probable mean temperature of 263° absolute centigrade or —10° centigrade.

Some writers have misinterpreted these remarks and understood us as supposing that there is a special layer at 4,000 meters elevation above sea level which prevents radiation escaping from below and whose own radiation passes unhindered to space. Our meaning was quite different. Every layer from sea level to the limit of the atmosphere contributes something to the total radiation output of the earth. But, because of the great absorption of superposed water vapor and clouds, the lower solid and liquid and atmospheric layers contribute little, while because of their dryness the higher atmospheric layers contribute little. Roughly estimating the various factors, we concluded that the center of activity of the radiation of the earth as a planet could be set at about 4,000 meters elevation.

How far are these conclusions now to be altered? As to the effect of cloudiness, not at all. As to water vapor, Mr. Fowle finds the following results on the percentages of absorption of rays from a perfect radiator at the earth's mean temperature in atmospheric columns containing besides carbon dioxide sufficient to produce maximum absorption, water vapor which if precipitated would produce certain depths of liquid water:

Ppt. water . . . cm . .	0. 003	0. 03	0. 3	3. 0
Absorption . . .	49	57	66	75

In order to apply these data I give figures for the average quantities of terrestrial water vapor which, according to Hann, exist in vertical columns from sea level to the limit of the atmosphere over different zones of the earth.

Latitude . . .	0–20°	20°–30°	30°–40°	40°–50°	50°–60°	60°–90°
Ppt. water . . . cm . .	4. 3	3. 1	2. 2	1. 6	1. 0	0. 6

From these figures it may be seen that the statement, "a tenth part of the average amount of water vapor in the vertical column of atmosphere above sea level is enough to absorb more than half of the radiation of the earth to space," is confirmed. But the conclusion therefrom that "nine-tenths of the radiation of the solid and liquid surface of the earth is absorbed by the water vapor of the atmosphere even on clear days" is not confirmed. Mr. Fowle has computed the absorption of the atmosphere in a state of humidity corresponding to 1.0 cm ppt. water, and finds it 72 per cent. Considering that the ppt. water in a vertical column over most of the earth exceeds 3.0 cm, it now seems probable that the proper figure should be eight-tenths instead of nine-tenths.

As regards the absorption of carbonic-acid gas Mr. Fowle finds that one-fortieth part of the amount of this gas found in a vertical atmospheric column produces the maximum possible effect. This does not lead to any modification of our conclusions as to the effect of atmospheric carbonic-acid gas as stated above.

With ordinary humidity, at sea level a layer of air 10 meters long, according to Mr. Fowle, will absorb 50 per cent of the radiation of a perfect radiator at terrestrial temperatures. Similarly the layer of air above 11 kilometers, or 6 miles, altitude contains enough water vapor to absorb 50 per cent of such radiation.

In view of what has been said and remembering the presence of clouds, only about one-tenth of the radiation of the solid and liquid surface of the earth escapes directly to space. The atmosphere above 11 kilometers apparently contributes more than half of the radiation of the earth viewed as a planet and prevents half of the radiation of lower layers from escaping. Nearly the entire output of radiation of the earth to space, certainly more than three-fourths, arises from the atmosphere and its clouds as its source. The "effective radiating layer," meaning a layer which if perfectly radiating to space would equal in radiation the actual earth viewed as a planet, may still be thought of as at several kilometers altitude and at a temperature well below freezing.

The subject of atmospheric absorption is so difficult both theoretically and experimentally that much more investigation ought still to be done on it. Mr. Fowle's long experience has well fitted him for making further advances. It is hoped to put at his disposal soon the necessary means to make new researches. These include bolometric apparatus of greatly increased sensitiveness, such as recent studies now enable us to construct. The one obstacle to complete success which now seems insuperable is the lack of any means to form an intense unabsorbed spectrum free from stray light, extending from 15 to 50μ in wave-length.

AT MOUNT WILSON.

The expedition of 1916 continued "solar-constant" and other observations at Mount Wilson until late in October. The expedition was renewed late in June, 1917. Improvements in the supply of electricity and water to the station were completed in June, 1917.

In 1916 many observations of the sky by day and by night were made at Mount Wilson with the pyranometer. The plan was followed from August to October of measuring with this instrument the total solar radiation at a fixed zenith distance of the sun, and almost simultaneously the total sky radiation over a fixed small area immediately surrounding the sun. It seems probable that as the brightness of the sky depends on the prevailing humidity and dust, and as the radiation of the sun is diminished by presence of humidity and dust, a method of combination of the two measurements may be found, adapted to give approximately the "solar constant." When computations are further advanced the matter will be tested.

Restandardization of secondary pyrheliometers in 1916 against our standard water-flow pyrheliometer indicated no change in their constants.

A vacuum bolometer was employed during a large part of the observing season. The sensitiveness was so much greater that considerable improvement in the work on the investigation of the distribution of radiation over the sun's disk was possible.

Redeterminations were made with great care on the form of distribution of the solar-energy curve outside the atmosphere. New mirrors of stellite, a very hard nontarnishing alloy, were substituted for the silvered mirrors of the spectro-bolometer. It is hoped that the work of 1916 will indicate conclusively how the sun's variations affect the distribution of energy in the solar spectrum.

FISCAL YEAR 1917–18.

AT WASHINGTON.

As heretofore the work of measuring and computing from the records obtained in the field on Mount Wilson has gone on steadily in charge of Mr. F. E. Fowle, aided by Miss F. A. Graves, computer, and Mr. R. Eisinger, messenger.

Mr. Fowle completed and published[5] his investigation of the absorption of long-wave rays by long columns of air containing known quantities of water vapor. His results give the relations between absorption and atmospheric humidity, wave length by wave length, from the visible spectrum down to waves of more than 20 times the maximum visible wave length, and for quantities of water ranging from $\frac{1}{200}$ to three times that which prevails in the vertical thickness of the atmosphere above Washington in clear spring weather. Many difficulties which were met required tedious subsidiary investigations which are described in the paper.

Notwithstanding the greatness of this contribution to meteorological science the subject of the relations of water vapor and terrestrial radiation demands yet more investigation adapted to cover the range of wave lengths from 16μ to 50μ, where Mr. Fowle was forced to give over the investigation temporarily, because no substance suitable to make a prism for forming the spectrum of these rays was known.

[5] Water Vapor Transparency to Low-temperature Radiation. Smithsonian Miscellaneous Collections, vol. 68, no. 8, 1917.

Mr. Aldrich has since investigated at the observatory a great number of natural crystalline and other substances, including many pure chemical preparations. None was found appreciably more transparent than rock salt, which was used by Mr. Fowle, except potassium iodide. Apparently this substance, if it could be procured in large crystals, or fused into a noncrystalline structure, would be suitable to carry the work to much longer wave lengths. Efforts have been made, as yet unsuccessfully, to procure blocks of this substance of suitable proportions and inner structure for making large prisms.

Mr. Aldrich has carried on a number of investigations on the absorption and reflection of atmospheric water vapor, liquid water, lampblack, gelatin, and other substances to rays emitted by a blackened reservoir filled with boiling water. In these experiments he has employed rock-salt transmission plates to roughly separate the total radiation into two parts, whose wave lengths are, respectively, greater and less than about 20μ, where rock salt ceases to be transparent. The results on water vapor agree well with what Mr. Fowle's spectrum work would tend to indicate. They also show that an atmospheric layer about 50 meters deep, containing water vapor equal to 0.05 centimeters of precipitable water, would probably absorb all the rays sent out by the 100° C radiator which are nontransmissible to rock salt; that is, above the wave length 20μ. This is in harmony with observations of the sun and of nocturnal radiation made by Mr. Aldrich on Mount Wilson, to which reference will be made below. The results on liquid water show it to be completely opaque in layers of 1 centimeter or more thickness to all rays of the above described 100° C radiation. The reflecting power of water surfaces to these rays varies with the angle of incidence as follows:

Incidence	0°	30°	55°	63°	70°	72°
Reflection %	2	3	7	10	17	22

From this it follows that though perfectly opaque in layers exceeding 1 cm thickness, water is not a perfect absorber or a perfect radiator for long-wave rays. It may be regarded as emitting about 90 per cent as much radiation as the perfect radiator at temperatures from 0° to 100° C.

Lampblack paint proved partially transparent and partially reflecting. Further experiments are required before publishing definite results, but evidently those who employ lampblacked surfaces in experiments with long-wave rays should consider these imperfections of radiating and absorbing power.

An investigation was made on possible regularities of periodicity in the short-interval variability of the sun[6] observed at our Mount Wilson station. Mr. H. H. Clayton had made such an investigation for the year 1913 and found indistinct tendencies toward a repetition of "solar-constant" conditions after intervals of

[6] On Periodicity in Solar Variation. Smithsonian Miscellaneous Collections, vol. 69, no. 6, 1918.

12 and 22 days. Computations were made here to extend the investigation to the other years from 1908 to 1916, excepting 1912.

Well marked relatively hot and cold hemispheres of the sun seem to have prevailed for several months in 1915, giving a "solar-constant" periodicity of about 27 days. In 1916 an extraordinary regular periodicity of $3\frac{1}{2}$ days seemed to be indicated. In other years tendencies to periodicities of other intervals were found, and generally more marked than in 1913, but not as prominently seen as in 1915 and 1916. On the whole the irregularity of period of the fluctuations of solar radiation would seem to be the most outstanding result of the inquiry.

In accordance with the wish expressed by Secretary Walcott, the facilities of the observatory have been employed whenever possible to assist in military investigations. This is not the time to detail the results of this effort further than to say that a large part of the work of the director and of Mr. Aldrich has been devoted to several such investigations, and with highly appreciated results. Naturally this has diminished the astrophysical output of the observatory.

CHILEAN EXPEDITION.

Preparations and arrangements for a South American solar-radiation expedition occupied much of the time of the director and that of the instrument maker. As stated in last year's report, a proposed expedition under the auspices of the Hodgkins fund to observe the solar radiation in the most cloudless region of Chile was temporarily postponed on account of the entry of the United States into war, and the expedition was diverted for a time to Hump Mountain in western North Carolina. Observations of the solar constant of radiation were made there, when weather permitted, until March, 1918. By that time it had grown to be certain that the site was too cloudy for the work, and, notwithstanding grave difficulties brought about by the war, the expedition was sent to Chile as originally proposed.

Director A. F. Moore and Assistant L. H. Abbot landed at Antofagasta, Chile, on June 16, 1918, with a large equipment of apparatus and supplies suitable to the investigation. They were greatly aided by the governor of the Province, the United States consul, and others, and the Chile Exploration Co. generously gave them the use of buildings and other valuable facilities at their disused mine at Chorillos, near Calama. Calama is a station on the railroad east of the nitrate desert, on the bank of the River Loa, at latitude N. 22° 28′, longitude W. 68° 56′, altitude 2,250 meters. Manuscript of daily meteorological records of two years, most kindly copied by Dr. Walter Knoche, former director of the Chilean Meteorological Service, leads us to hope for as many as 300 days per year favorable to solar-constant work there. The experiments are to be continued daily, as far as possible, for several years. They should furnish meteorologists with a firm basis for estimating the effects of the solar variability on the terrestrial climate.

TOTAL SOLAR ECLIPSE.

Owing to the pressure of military investigations our preparations for observing the total solar eclipse of June 8, 1918, were not extensive. The observations proposed were confined to observing the eclipse phenomena visually, photographing the solar corona, and determining the sun and sky radiation during the partial phase, and the "nocturnal" radiation during the total phase by means of the pyranometer.

Necessary apparatus was prepared at the observatory shop. It comprised parts for two 11-foot focus cameras, each of 3 inches aperture with equatorial mounting and driving clockwork, and two pyranometers. The observations were in charge of Mr. L. B. Aldrich, who was assisted by Mr. A. Kramer and by Rev. Clarence Woodman, a volunteer observer who had aided us in 1900.

The station selected was near Lakin, Kansas, not because it was the most favorable, but because the more favorable parts of the eclipse track farther west would be occupied, it was known, by many eclipse parties, so that the chances of having clear weather at some station were materially increased by the choice of one so far east as Kansas. Magnetic observers sent out by Dr. Bauer were also at Lakin, and, being already on the ground, aided materially in establishing Mr. Aldrich's party.

The observers chose the site on Monday, June 3, and were hospitably entertained at the home of Mr. Pittenger, a rancher. The cameras were set up in a barn looking out westward through a slot cut away for the purpose. Unfortunately, cloudy and rainy weather hindered the preparations and prevented the rating of the clock and the photographic focusing of the lenses on the stars, so that the adjustment could be made but roughly.

On eclipse day, Saturday, June 8, no hope was felt of fair weather during the forenoon, but fortunately the sky became nearly free from clouds about 1 o'clock, and continued so until after nightfall and during Sunday. All times of contact were observed by Rev. Dr. Woodman, who also exposed the cameras, as follows :

Latitude	37°	53′	04.2″ N.
Longitude	101	17	51.3 W.

Contacts (Greenwich mean time):

	h.	m.	s.
First	10	19	48.5
Second	11	27	15.1
Third	11	28	37.3
Fourth	12	29	45.4

The observers regarded the eclipse as unexpectedly dark and the phenomenon as more than usually grand.

Very good photographs of the corona were obtained, showing extensions to about 3 diameters of the sun in some directions. Owing to lack of opportunity to rate the clock there was some evidence of imperfect following. The negatives were developed, with the kind permission and advice of Director E. C. Pickering, by Mr. King at Harvard College Observatory.

Messrs. Aldrich and Kramer observed successfully throughout the afternoons and early night hours of June 8 and June 9 with the pyranometer. The results obtained measure the gradual diminution of the radiation of the sun and of the brightness of the sky as the eclipse progressed, the outgoing radiation from the earth's surface during totality, the gradual increase of sun and sky radiation afterwards, their decline toward sunset, and the outgoing radiation from the earth's surface after nightfall. Numerical values will be published later.

WORK AT MOUNT WILSON.

Mr. L. B. Aldrich occupied the Mount Wilson station until October 11, 1917, and again after June 14, 1918. He continued the usual solar-constant determinations and the determinations of the distribution of radiation over the sun's disk. Two improvements were introduced in the apparatus.

The coelostat used in solar-constant work was provided with stellite mirrors in place of silver-on-glass, so that now the optical train of the spectrobolometer for solar-constant work contains exclusively nontarnishable mirrors. This allows us to compare as never before the distribution of radiation in the solar spectrum from day to day. We hope now to determine surely whether the variations of solar radiation are uniform over the whole spectrum or predominate in certain wave lengths.

A specially designed vacuum bolometer like the one employed at Hump Mountain and in Chile and wholly sealed in glass so as not ever to require attention to renew the vacuum has been substituted. This bolometer was constructed to exact specifications as to length, breadth, and thickness of strips in accordance with completely worked-out unpublished theory of the bolometer. We are sure that it is the last word on the subject as regards adaptability to our investigation. All expected results are obtained in its actual use.

The sky was more cloudy than usual on Mount Wilson both in 1917 and 1918, during the time of our expeditions. In the winter, in November, December, and January of 1917–18, the Carnegie Institution observers reported unusually good weather for the season.

Mr. Aldrich carried on in 1917 some investigations to determine whether long-wave rays, not transmissible by rock salt (that is, exceeding 20 μ in wave length), occur in the solar beam at the earth's surface. The experiments indicated that they do not. He also investigated the transmissibility of the atmosphere for rays of more than 20 μ in wave length by means of the pyranometer with and without a rock-salt cover. The experiments showed that even toward the zenith these rays are wholly cut off by the lower layers of the atmosphere. Hence we may conclude from both the solar and noctural observations that our atmosphere is opaque to rays exceeding 20 μ in wave length, such as are emitted in recognizable quantities by bodies at terrestrial or solar temperatures. This result is in harmony with Mr. Aldrich's laboratory experiments above mentioned.

In June, 1918, experiments were begun at Mount Wilson to determine the distribution of solar radiation along that diameter of the solar image which is at right angles to the east and west diameter investigated in our usual tower-telescope work. A special apparatus was arranged to slowly rotate the second mirror of the coelostat, and thus produce a regular drift of the solar image along any desired diameter. Preliminary results obtained show that the differences, if any, between the distribution of radiation along different solar diameters do not amount to 1 per cent.

PERSONNEL.

R. Eisinger resigned from our service in June, 1918, and after service in the Treasury Department enlisted in the Navy.

FISCAL YEAR 1918-19.

AT WASHINGTON.

As usual, the computation of the results of solar-constant observations made at Mount Wilson, California, has gone on steadily at Washington, except as interrupted by the furlough of the computer, Miss Graves, for work in France, as mentioned under the subheading "Personnel." After the services of other computers had been obtained the work went on rapidly and is now nearly up to date.

The preparation of Volume IV of the Annals of the Astrophysical Observatory, including results of measurements from the year 1913, has been occupying the attention of the director to a very great extent since February.

In consideration of the fact that the total eclipse of the sun of May 29, 1919, was visible in La Paz, Bolivia, which is not very far from the Smithsonian solar-constant observing station in Calama, Chile, and in further consideration of the fact that the Argentine Government was using the daily telegraphic reports of the solar observations at Calama for forecasting purposes; and, further, that certain conditions had arisen at Calama which seemed to require the personal investigation of the director, it appeared necessary to make an expedition to South America to attend to these several matters. The preparation for the eclipse work occupied some time of the director and of the instrument maker.

Several investigations relating to the war, a brief note of which was mentioned in last year's report, were continued during the fiscal year.

The painstaking and valuable work which Mr. Fowle has been doing on the revision of the Smithsonian Physical Tables should receive some notice, although this work is being done by him outside of his regular hours of service for the observatory. This book has passed through a number of editions under his editorship and has attained an enviable reputation in this country and abroad for the accuracy and fullness of its contents. The new edition, which is now in press, has received unusual attention on his part, and very valuable cooperation from the various scientific departments of the Government and of outside individuals in colleges and industrial corporations and elsewhere, and will be a great advance over any of the former editions.

In connection with work of the observatory, we have long wished to determine the solar constant of radiation by a method which does not involve the assumption that the transparency of the atmosphere is constant over the two or three hours required for the determination of it by the usual spectrobolometric method. We hoped that, seeing that the sky is brighter when the transparency is less, an observation by the pyranometer, or some other more suitable instrument, of the brightness of the sky in the neighborhood of the sun, combined with the usual measurements of the pyrheliometer and perhaps of the spectrobolometer, but only at one period of time, might be sufficient to determine the solar constant by a satisfactory empirical process based upon spectrobolometric investigations of former years. In the hope of getting an instrument more satisfactory than the pyranometer for this special work, a new design comprising essentially two disks, one of which is shined upon through a graduated aperture by the sun and the other of which is exposed to the small region of sky desired and both connected by thermoelectric junction so as to enable equality of temperature of the two disks to be adjusted, was devised and partly constructed at Washington. It was mailed to Calama, Chile, and was finished by the director during his visit in Chile and is now in satisfactory operation, although it has not yet supplanted the pyranometer for the purpose in question.

Another problem which requires a new kind of apparatus is the measurement of nocturnal radiation such as the earth sends out to space. This investigation is exceptionally difficult, for it involves a range of wave length from 5μ to 50μ. There is no surface either of blackened metal or other substance which is fully absorbing to the rays throughout this whole extent, and furthermore there is no optical medium known by means of which the properties of the rays beyond about 17μ, where rock salt ceases to be transparent, may be investigated. For the purpose of determining nocturnal radiation it seems absolutely indispensable that there should be devised an instrument based upon the principle of the perfect radiator or "absolutely black body." This is a very difficult thing because not only does the instrument have to be exposed to the full hemisphere of 180° of solid angle, but also the radiation to be observed is small in amount, little more than the tenth part of the radiation of the sun. Seeing that the "black body," so called, requires to be a hollow chamber, large with respect to the aperture through which the rays enter, the rise of temperature of its walls which must be measured is extremely small. After much consultation, Mr. Aldrich and the director decided upon a design for a new instrument for this purpose. This was constructed in the spring of 1919, and is now in use on Mount Wilson. Whether it will prove to be satisfactory or not remains a question.

In order to investigate the rays beyond the wave length where rock salt becomes opaque a great many measurements have been made by Mr. Aldrich, as mentioned in the last report, to attempt to find some substance transmissible to such rays. The best substance found appeared to be potassium iodide. It usually occurs as crystals no larger than a buckshot. Accordingly, in order to make any satisfactory progress it was necessary to procure larger crystals, preferably large enough to make a prism of 5 or more centimeters on an edge, but at least so large that such a prism could be built up by cementing parts of it together. Experiments had been made at the General Electric Co. for producing large crystals needed in war operations, and they very kindly undertook to try to grow potassium-iodide crystals also. A number of crystals, very satisfactorily clear, have been produced by them as large as 2 centimeters on each edge, and from a sufficient number of these the prism required for going on with this long wave length work may probably be formed.

Mr. Aldrich spent a long time on the development and testing of an apparatus for determining the constant of the fourth-power radiation formula ordinarily called σ. This is a very difficult research. The quantity is already certainly known within 5 per cent and many physicists would believe even closer than this. Many researches have been made upon it and in order to do a piece of work worth while it is necessary to show that it is certainly accurate to 1 per cent. After many experiments it was found that this degree of certainty could not be secured with the apparatus which Mr. Aldrich and the director had designed and which Mr. Kramer, the instrument maker, had constructed, and so the work was given over for a time.

AT MOUNT WILSON.

Mr. Aldrich continued the observations of the solar constant of radiation until the middle of October, 1918, and returned to continue them early in June, 1919. In September of 1918 he made a very interesting observation in cooperation with the Army Balloon School at Arcadia at the foot of Mount Wilson. It consisted in arranging a pyranometer to be hung below the basket of a captive balloon, which could be raised above the level of the great horizontal layer of fog which often covers the San Gabriel and other valleys in the neighborhood of Los Angeles in a sheet many miles in extent. On this occasion the layer of fog extended from 1,000 feet of altitude to 2,500 feet. The balloon was raised to about 200 feet above the layer. An officer of the balloon school exposed the apparatus under the balloon to the radiation from the sheet of fog, while Mr. Aldrich, on the ground, observed the deflections of the galvanometer. The galvanometer was connected to the pyranometer by a pair of wires about a half mile long. Simultaneously observations were made on Mount Wilson with the pyrheliometer to determine the exact character of the day, and on other days of similar character Mr. Aldrich exposed the pyranometer to the radiation of the sun and sky combined. Thus knowing the radiation reflected from the sheet of fog, and knowing the radiation on a similar day coming down from the sun and sky, he was able to determine the reflecting power of a great layer of fog. This observation is very useful for the study of the relations of the temperature of the earth to radiation. The result of the experiments, which were continued for several hours without interruption, was very satisfactory. The final value for the reflecting power of a great horizontal sheet of fog was 78 per cent.

The weather on Mount Wilson, in the autumn of 1918, was uncommonly poor for the solar-constant work, as rain fell frequently and a great many clouds came up. Altogether it was the most unfavorable weather which has been experienced in any observing season there since it has been occupied for solar-constant purposes.

SOUTH AMERICAN EXPEDITION.

Several considerations led to the decision to make a small expedition to South America in the spring of 1919. The Institution had equipped an observatory at Calama, Chile, to measure the solar constant of radiation. The Argentine meteorological service, through its chief forecaster, Mr. Clayton, had been determining the effects of the variation of the sun on the temperature and other weather conditions of the earth, and had been so much impressed by the value of the solar-variation observations for forecasting purposes that they had arranged to receive daily telegraphic reports of the values obtained at Calama, Chile. The director of the observatory at Calama, Mr. Moore, had conceived a feeling that the sky conditions were not as favorable as perhaps might be secured in other parts of South America or elsewhere and feared that it was unwise for the Institution to continue to conduct the operations there. On all of these accounts it seemed necessary for Dr. Abbot to go to South America and deal with these several matters.

Total solar eclipse.—In accordance with the sundry civil act, which failed of passage on March 4, 1919, but was approved July 19, 1919, the following authorization was secured:

> The unexpended balance of the appropriation "For observation of the total eclipse of the sun of June 8, 1918, and so forth," is reappropriated and made available for observation of the total eclipse of the sun of May 28, 1919, visible in Bolivia.

The two 11-foot focus 3-inch cameras employed by the Smithsonian observers at Wadesboro, North Carolina, in 1900, and again by Mr. Aldrich in 1918, were equipped with a collapsible tube and other mechanism, so that they could be speedily arranged with equatorial clock-driven motion to photograph an eclipse in South America. Mr. Moore, at Calama, was instructed to arrange to join Dr. Abbot with the pyranometer employed there, so as to observe the degree of darkening of the sky and sun as the eclipse progressed. Arrived at Calama, the apparatus was repacked for use in the field, and Messrs. Moore and Abbot proceeded to La Paz, Bolivia, where, owing to the kindness shown by Mr. Babbage, of the railroad, arrangements were made to observe close to the railroad station at El Alto, situated about 1,500 feet above La Paz, at an altitude of about 14,000 feet above sea level. The day of the eclipse, May 29, proved very favorable. The sky was entirely cloudless in the neighborhood of the sun for several hours. Mr. Moore had observed during the day before and during the night, and continued his observations each minute throughout the totality and the succeeding partial phase up until about two hours after sunrise. Dr. Abbot had set up and adjusted the photographic telescope with Mr. Moore's aid, and except for one defect it operated perfectly. This was that since the eclipse took place so very early in the morning, only 20 minutes after sunrise, the rate of motion of the sun above the horizon was not uniform with that which would occur in the middle of the day, owing to refraction. The apparatus had only been set up the day before, so that there was not time to work out this matter to know exactly how to rate the clock at the moment of eclipse. Preliminary observations of May 28 had indicated that the clockwork ran a little too slow. During the day it was speeded up a little, but on the day of the eclipse it proved to be a trifle too fast, so that the moon appears to be elliptical rather than perfectly round, as it should have been, except for the slight motion of the moon relative to the sun during the eclipse. However, this defect is not very noticeable, and excellent photographs were obtained with both lenses, but particularly with the one which was exposed 1 minute and 30 seconds rather than the other, which was exposed $2\frac{3}{4}$ minutes.

The phenomenon was uncommonly grand. The sun had risen over a snow-capped mountain, about 20,000 feet high. It rose over half eclipsed, with the crescent horns pointing upward from the horizon equally. In 20 minutes totality occurred, and there shot out over 20 fine sharp coronal rays, greatest elongated along the equatorial zone, but also visible to great distances from the poles. At the lower limb there was a very large flaming red prominence, which at that time rose to perhaps a quarter of the solar radius, and had a very long side extension, after the manner of a hook. The same prominence was observed by spectroscopic methods in the United States, at the great observatories, and was one of the finest prominences ever photographed. It is very interesting and fortunate that the early history of this prominence was enriched by the photograph made at La Paz so very early in the morning.

Taking the whole phenomenon together, the snow-covered mountain, the brilliant sky at that great altitude of 14,000 feet, the very numerous and long coronal streamers, and the enormous crimson prominence casting its glow over all, the spectacle was truly glorious, and by far the most impressive of any of the eclipses which have been seen by the writer. It was reported that the Bolivian natives lighted many fires and supplicated the sun to return, after old Inca traditions.

Visit to Argentina.—Immediately after the eclipse Messrs. Moore and Abbot proceeded to La Quiaca in Argentina for the purpose of having a conference there with the director and forecaster of the Argentine meteorological service. Mr. Clayton, the official forecaster, submitted for their inspection results he had obtained during several years in the comparison of the weather of Argentina with the variations of solar radiation reported by the Smithsonian observers at Mount Wilson, California, and Calama, Chile, and the results obtained by using the measurements of Calama for the forecasting of the weather in Argentina.

Mr. Clayton says:

For nearly a year numerical and graphical analyses have been made of the solar variations and of the variations of temperature at 20 selected stations well distributed over Argentina, Chile, and Brazil. These analyses show that each variation in solar radiation has been followed by similar variations of temperature in South America, with a few exceptions that may easily have resulted from errors in the measurements of solar radiation. At Buenos Aires the ratio of temperature change to solar change at the time of greatest solar activity was found from the averages of several years to be 1.4° C. for each change of 1 per cent in solar radiation. Since the extreme solar values range about 6 per cent on either side of the mean, there might result departures from the normal at Buenos Aires from this cause of about 8.5° C. The extreme departure from the normal observed at Buenos Aires during the last 13 years has been 11.5° C. The results of these researches have led me to believe that the existing abnormal changes which we call weather have their origin chiefly, if not entirely, in the variation of solar radiation.

Naturally, these results, which are supported by an enormous amount of careful and conscientious computation on the part of the forecasting division of the Argentine meteorological service, are of extreme interest. They point to the great desirablity of equipping in different cloudless regions of the world several observatories designed for the measurement of the solar constant of radiation. The chief of the Argentine weather service, Mr. Wiggin, desires very much to take over the South American station of the Smithsonian Institution to be maintained by the Argentine meteorological service. Tentative arrangements were entered into between Dr. Abbot and Mr. Wiggin for this purpose, which, however, require the further approval of the Argentine Government to become effective. If suitable arrangements for the transfer can be made, it is hoped to employ the funds thereby set loose for the establishment by the Smithsonian Institution of a solar station in Egypt.

From Argentina, Messrs. Moore and Abbot returned immediately to Calama.

Measurements of the Solar Constant of Radiation at Calama, Chile.—When Dr. Abbot reached Calama he found that Messrs. Moore and Abbot had prepared data giving the pyrheliometry, the transparency of the atmosphere for nearly 40 wave lengths, the function ρ/ρsc, and pyranometer values representing the intensity of the radiation of the sky in a zone 15° wide surrounding the sun. All these values were tabulated with solar-constant values for 60 days of observation and for each day at periods when the air masses were 2 and 3, respectively.

We have felt very keenly the desirability of devising some method of determining the solar constant of radiation which would be independent of changes in the transparency of the atmosphere during the period of observation. It had been hoped that this might be done in some simple way by the aid of the pyranometer, that instrument which we devised several years ago for the purpose of measuring the brightness of the sky. It is well known that when the sky becomes more hazy the direct beam of the sun is reduced in intensity, but the scattered light of the sky at the same time is increased. Accordingly, it would seem that a pyranometer measurement of the brightness of a limited area of the sky near the sun would furnish an index of the state of the transparency of the atmosphere at the moment of observation, and this combined with the usual observations of the solar intensity at the earth's surface by the pyrheliometer, and combined further with the determination of the quantity of the aqueous vapor between the observer and sun (which is indicated by the state of the great infra-red absorption bands, ρ and φ) might give the means of estimating the solar radiation outside the atmosphere from observations made at a single instant of time.

With the various data mentioned above as a basis, the writer endeavored to find some method of determining the solar constant of radiation without the necessity of treating the several wave lengths of radiation separately, but after almost a week spent in working over the data, trying to combine them along these lines, the effort had to be abandoned. Mr. Moore had, however, suggested that if we knew the coefficient of atmospheric transmission for all of the individual wave lengths on a given day and had observed with the spectrobolometer and pyrheliometer at air mass 2 or at air mass 3, we could determine the solar constant from these data at once. All simple means having failed to give a satisfactory method, Mr. Moore's suggestion was acted upon, and it was found possible, by noting the value of the function ρ/ρsc and the intensity of the sky light in the neighborhood of the sun, to determine at once the transmission coefficients for all wave lengths. This we do by means of plots in which the data for the 60 days mentioned are employed. These data were used in the following manner:

Taking the value obtained at air mass 2 by the pyranometer for the limited area of sky around the sun, dividing it by the value of ρ/ρsc at the corresponding time, we obtain a function which we may call "F." Plotting values of "F" as abscissæ against values of the transmission coefficients for each measured wave length as ordinates, we obtain about 40 plots. These for the infra-red region of the spectrum are nearly straight lines but they become more and more convex toward the axes of coordinates for the rays of shorter wave lengths. In the 60 days which were available for the investigations the function "F" ranged through values running from 100 to 900 of a certain scale, while the function "a"—that is, the transmission coefficient—ranged only through a very few per cent and for a large portion of the spectrum, including the infra-red region, hardly through more than 1 or 2 per cent. Accordingly great error is allowable in the function "F" without greatly affecting the accuracy of the inference as to the value of the function "a." In short, by means of the function "F" we are able to determine the function "a" for all wave lengths with highly satisfactory accuracy from observations at a single point of time, so that changes of the atmospheric transparency during the period of observation are avoided.

This new method will hereafter be employed by the Smithsonian observers at Calama in combination with the old, not only for air mass 2, but for air mass 3, and they will check one against the other frequently for a considerable period of time until we are abundantly satisfied of the accuracy of the new method of observation. Hitherto the new method has enabled us to save at Calama a number of days of observation which, owing to the obvious changes in transparency of the atmosphere, due to formation or disappearance of clouds, would otherwise have been lost.

So far as we have as yet been able to compare the results by the old and the new methods, they are on the average closely identical. For instance, on July 1 three values of the solar constant were computed: (1) By the old process; (2) from observation at air mass 2; (3) from observation at air mass 3. The results obtained were as follows: 1.948, 1.940, 1.955, all agreeing within less than 1 per cent, and the mean of the results by the new process agreeing identically with the result by the old.

The new process requires but two or three hours of work, where the old required about 15, so that if it continues to appear as satisfactory as now a very great gain in labor will result from it. Not only is this so, but a still greater gain, we think, will come in accuracy, for we have now eliminated the fruitful source of error, depending on the variability of the atmospheric transparency during the observations.

The new method of determining the solar constant of radiation is not applicable to other stations than Calama without a new series of contemporaneous solar-constant determinations by the old method and pyranometer observations at air mass 2 and air mass 3 to use with them. We have not at present available the necessary pyranometer observations at Mount Wilson, but we shall undertake to obtain them at the earliest practicable moment, and hereafter it is probable that the new method of determination will be employed there as well as in South America.

On the whole, the expedition to South America was unexpectedly fruitful. First, satisfactory observations were made of the eclipse, including both photographic observations of the eclipse phenomenon and pyranometer observations of the brightness of the sky during its progress. Second, a very interesting conference was held with the chief and chief forecaster of the Argentine meteorological service, in which they explained their investigations of the application of solar radiation measurements to weather forecasts and indicated their high opinion of the value of solar-radiation work for weather forecasting. Third, investigations at Calama based upon the observations there indicated a new empirical method of determining the solar constant of radiation, which appears to be equally as accurate as the old and to have the great advantages: (1) That it avoids the assumption of uniformity of atmospheric transparency during the several hours formerly required for observing, and (2) that it diminishes the time required for computing the result from about 15 hours to about 3 hours.

PERSONNEL.

Miss Florence A. Graves, computer, was placed on furlough beginning September 5, 1918, in order that she might take up work in connection with the Red Cross operations in France.

Miss Gladys L. Thurlby reported as assistant computer on December 2, 1918, and Miss Inez A. Ensign reported as computer on February 1, 1919.

FISCAL YEAR 1919-20.

AT WASHINGTON.

Much labor was expended on the preparation of tables of results for publication in Volume IV of the Annals of the Observatory.

Under Mr. Fowle's direction, the Mount Wilson observations of 1919 were reduced and compared with those obtained by Smithsonian observers in Chile. An experiment had been made in using rolled stellite instead of cast stellite to prepare new spectroscope mirrors for the South American work. As these mirrors were not quite finished when Director Abbot went south to observe the eclipse of May 29 (as related in last year's report) he took with him the Mount Wilson spectroscope mirrors, intending that the new ones should replace them on Mount Wilson. Unfortunately, they proved unsuitable owing to a gradual alteration of figure after completion, but were nevertheless used on Mount Wilson by Mr. Aldrich for the experiments of 1919.

The matter is mentioned here because the defective mirrors introduced stray light in the spectrum, which led to a systematic error of 2 per cent (in defect) in the Mount Wilson solar-constant values of 1919. Considerable additional labor was required in the reductions on this account. Furthermore, the sky was unusually hazy and streaky on Mount Wilson in 1919, which also added to the labor and anxiety of determining the best values from the observations.

Agreement of Mount Wilson and Chilean work.—However, the results when finally worked out proved to agree excellently, except for the systematic error above mentioned, with the results obtained in Chile. Both stations showed simultaneous and nearly equal fluctuations of solar radiation through a range of about 5 per cent. After allowing for the aforesaid 2 per cent systematic error of Mount Wilson, the average deviation of the two stations was but 0.013 calorie, or 0.65 per cent from all the values, about 50 in number, obtained on corresponding days. Omitting five values very discordant, when the Mount Wilson sky was very hazy and streaky, the average deviation of the remaining days was about 0.008 calorie, or 0.4 per cent.

Solar variation confirmed by observations of Saturn.—From correspondence with Dr. Guthnick, of the Berlin-Babelsberg Observatory, a most interesting confirmation of the solar variability has appeared. Variations of brightness of the planet Saturn from January to May, 1920, were shown by Dr. Guthnick's photo-electric observations which could not be accounted for after allowance for all known sources of variability. These outstanding variations were found to be in almost exact correlation with fluctuations of the solar radiation as observed at Calama, Chile. One per cent increase in solar radiation was found to accompany 1 per cent increase of Saturn's brightness.

These results, however, were only derived in connection with one of two possible interpretations of the nature of solar variation. The sun might vary in such a manner that its changes would be observed simultaneously in all directions and so would occur on identical days on all the planets. This hypothesis *does not fit* the available observations of the sun and Saturn. On the other hand, the solar radiation may be unequal in different directions. Such inequalities are, in fact, indicated by the ragged ray-like structure of the solar corona. On this hypothesis a change of solar radiation would occur as ray after ray strikes the earth in the course of the sun's rotation upon its axis. These same unequally intense rays would reach the planet Saturn either before or after they reached the earth, according to the relative heliocentric longitudes of the earth and Saturn. The sun rotates about 14° a day, so that the angular difference in position of the two planets is to be divided by 14° to indicate the number of days allowance to be made between the dates of corresponding solar and Saturnian measurements.

Proceeding on this second hypothesis, extraordinarily close correspondence between the variations of the sun and Saturn was found. Further work of the kind is to be done at Saturn's next opposition. It will be noted that this second hypothesis of the nature of the solar variation relieves us of the great difficulty of understanding how so immense a body as the sun could vary in radiation so rapidly as our observations indicate. We have now only to suppose that there are inequalities of radiation in different directions which may be due to the absorption or scattering of the rays in the coronal regions near the sun. These inequalities may persist with little alteration for weeks. We, however, note them as variations of solar radiation as they sweep by us in the course of the sun's rotation on its axis.

The honeycomb pyranometer.—Mr. Aldrich constructed two copies of a new instrument devised by Abbot and Aldrich for measuring "nocturnal radiation." We call it provisionally the "honeycomb pyranometer." In this instrument a long thin ribbon of "therlo" resistance metal about one-half inch wide and one-one-thousandth of an inch thick is bent in such a way as to make up into 200 cells of triangular cross section all included in a total cross-sectional area of about 1 inch square. The corners of the cells are electrically insulated with baked shellac so that a current of electricity can be caused to flow from end to end of the ribbon and thus all around each cell. Radiation which enters the front of the cells from any source, if not absorbed there is reflected to and fro within the cells till it reaches their rear ends. There its remnant emerges upon a silvered mirror inclined at a small angle so as to throw back the rays to make a second course to and fro toward the front. Thus by repeated absorptions the rays are at length almost wholly converted into heat. The device is, in short, a "black body." But unlike other "black-body" receivers, its central cells are protected from losses of heat to the sides by reason of the nearly equally warmed cells surrounding them. Thus the instrument is almost as sensitive as a flat blackened strip, but possesses the valuable property of being fully absorbing, which a strip does not. The temperature difference between the central cells and the case of the instrument is indicated by thermo-electric elements. By passing a proper electric current through the "therlo" ribbon the same temperature difference can be produced as by radiation. The known energy of the electric current becomes the desired measure of the energy of radiation, as in Ångström's pyrheliometer. Also the constant of the apparatus is calculable from the known dimensions of it. It is possible, too, to observe the solar radiation with this instrument, and so to calibrate it. Measurements of this kind check very closely with the computed values.

Messrs. Aldrich and Abbot made a series of measurements with the honeycomb pyranometer on various sources of radiation, including comparisons with the ordinary pyranometer on incandescent lamps of different kinds, and also observations on large hollow radiators at different constant temperatures. Values of the constant of the fourth-power law of radiation differing by only 1 per cent from the best accepted value were readily obtained in this latter work. On the whole the "honeycomb pyranometer" is an instrument of great promise for standard measurements.

Experiments on the constant "sigma."—In collaboration with Dr. C. E. Mendenhall, a new attempt was begun to devise means to measure the constant of radiation with greater certainty. Apparatus was devised and constructed in the observatory shop for this purpose. There was not time to try it before the departure of Messrs. Abbot and Aldrich into the field, so that the apparatus was loaned to Dr. Mendenhall for trial at the University of Wisconsin.

FIELD WORK AT MOUNT WILSON.

Mr. Aldrich continued observing on Mount Wilson until October, 1919. As said above, the year was unfavorable both by reason of a defect in equipment and by reason of much haze, cirrus cloud, and streakiness of sky. Also on many days a curious wandering of the galvanometer needle occurred. This phenomenon has been noted at Mount Wilson occasionally in former years, but was unusually pronounced in 1919. By anticipation, it may be remarked that it occurred also very markedly in late July and in August, 1920. The march of the galvanometer spot in these wanderings is relatively slow. A centimeter or two back and forth upon the scale in one or two minutes is the usual magnitude. It occurs with the galvanometer unconnected to the bolometer. Reastaticising of the needle system till it turned in the earth's field at the same rate as the supporting quartz fiber failed to cure the trouble. The Mount Wilson expedition was renewed in June, 1920, by Messrs. Abbot and Aldrich.

PROPOSED STATION IN ARIZONA.

The prevailing cirrus cloudiness and haziness at Mount Wilson in all recent years, greatly exceeding that which obtained from 1905 to 1910, when the station was new, has been very discouraging. Furthermore, the station is quite unsuitable for "solar-constant" work in winter and spring months owing to cloudiness. It is urgently desirable to observe the solar radiation daily, as far as possible, in the United States, in order to check the results which are being obtained by Smithsonian observers in Chile.

Accordingly it seemed best to set up a station in the most cloudless region of the United States, where the work could go on during the entire year. Chief Marvin, of the Weather Bureau, obligingly caused investigations to be made of various proposed sites in California, Nevada, and Arizona. The one of highest promise appeared to be on the Harqua Hala Mountain (elevation about 5,800 feet) near Wenden, Arizona. Congress was urged to appropriate $25,000 for the establishment of a first-rate "solar-constant" observing station at the best site, but the appropriation failed.

At this juncture Messrs. Abbot and Marvin held a long discussion by correspondence and verbally as to the reality of the supposed solar variability, and its availability as a forecasting element, in view of the use being made of the Smithsonian solar observations in Chile by the Argentine and Brazilian weather bureaus. The discussion brought out very clearly the urgency of obtaining corroborative observations of the solar radiation daily in the United States.

Fortunately the proposed new station obtained private financial support in the lack of congressional action. Mr. John A. Roebling, of Bernardsville, New Jersey, at Dr. Abbot's solicitation, made a grant of $11,000 for promoting measurements of solar radiation. Mr. Roebling made the condition that so much of this sum as necessary should be devoted to removing the Smithsonian station from the plain near Calama, Chile, to a mountain site above the reach of dust and smoke. Any balance remaining after this improvement of the Chilean station could be used for the removal of the Mount Wilson equipment to the Harqua Hala Mountain in Arizona, or for such other purposes as Dr. Abbot might prefer for the advance of the study of solar radiation.

At a cost of between $4,000 and $5,000 the Calama station was removed to a mountain about 10 miles south of Calama, where skies of extraordinary purity have been experienced. The removal was completed and first observations made at the mountain shortly after the close of the fiscal year.

Dr. Abbot visited Wenden, Arizona, and the Harqua Hala Mountain in the last week of June, 1920. Contracts were made for the erection, on the summit, of a stone and adobe building of two stories, a lower, partly underground, for observing, and an upper for quarters of observers. This is to be ready for occupancy by September 15, 1920, when it is proposed to remove the "solar-constant" observing equipment from Mount Wilson to Harqua Hala.

The purpose of these improvements is to enable us to obtain nearly every day in the year first-rate check observations of the "solar constant" of radiation at two stations remote from one another in the two hemispheres. Only thus is it possible to lay a firm foundation of solar observations extending over a considerable interval of time, which will enable meteorologists to determine if the sun's variations are really of value as a weather-forecasting element. In view of the results published by Mr. H. H. Clayton, of the Argentine weather service, there is sufficient evidence that this may be the case to warrant the expense and discomfort attending the continuous occupation of two desert mountain observatories like Harqua Hala and the Chilean station.

Great appreciation is due Mr. John A. Roebling for his generous aid in stepping into the breach at this time when it proved impossible to obtain public support for the urgent need. Only the most primitive equipment has, it is true, been possible on the Harqua Hala Mountain with the means available. Unfortunately, too, it means a considerable restriction of other interesting investigations under way or proposed, owing to the partial dismantling of the Mount Wilson station. This is greatly to be regretted. It is recommended that Congress be urged to appropriate the money needed to complete the independent equipment of Harqua Hala, so as to permit needed apparatus to return to Mount Wilson. The Harqua Hala station should also be relieved of its limitations of water, of accessibility, and of communication, and the buildings made more commodious. Otherwise it will be only at such personal sacrifice of comfort as few can be found willing to make that its work can go on.

PERSONNEL.

Miss Inez Ensign resigned as computer on September 22, 1919. Miss F. A. Graves returned as computer from leave for overseas work in France on September 4, 1919. Miss Gladys Thurlby, computer, married, on May 8, 1920, Mr. Albion M. Bond, but remained in the service of the observatory.

Chapter II.

NEW INSTRUMENTS FOR SOLAR CONSTANT WORK.

1. THE VACUUM BOLOMETER.

In all the researches on the solar-energy spectrum we have employed the instrument invented by the late Dr. S. P. Langley about 1880, which he called the bolometer. As is well known it consists of a delicate electrical thermometer whose sensitive parts are two fine tapes of metal, blackened, one of which is exposed to the rays to be measured while the other one is hidden behind an appropriate diaphragm. The tapes are joined with suitable resistance coils and made up into a Wheatstone's bridge which is brought to a balance. A change of temperature of the exposed strip with reference to the hidden one destroys the balance slightly and the effect is measured by a sensitive galvanometer.

In Volume I of these Annals, page 51, we find a footnote which states: "The bolometer case as now constructed is the product of years of slow elimination of undesirable conditions rather than of the sudden introduction of any new device; but as it is shown in Plate 12A it represents an actual working case into which several pieces that were formerly distinct have been introduced and not the least important of these changes is the introduction in the very case of the bolometer itself of what used to occupy a large distant resistance box, now practically dispensed with." The illustration referred to shows a very complicated piece of apparatus, including the two sensitive tapes, coils for completing the Wheatstone's bridge and the complex arrangement of a slide wire operated mechanically from without for bringing the bridge to a balance.

In Volume II of the Annals, Plate VIII shows a somewhat simpler but yet complicated contrivance for the same purpose, also including a slide-wire device operated mechanically from without.

In Volume III of the Annals, at page 34, we describe a simpler device for balancing the bridge in which the slide wire and the complicated mechanical contrivances for operating it are done away with, and in their place is substituted a large, variable shunt placed about one of the balancing coils of the bridge. We state in a footnote: "We are now accustomed to using this shunt method for balancing for all our bolometric apparatus except that on Mount Wilson.[1] There are three decided advantages in the shunt method over a slide-wire adjustment: First, that there are no irregularities of balancing due to change in contact resist-

[1] It has long since been introduced there, too.

ances; second, that the sensitiveness of the bolometric apparatus and the degree of uniformity of the galvanometer scale may be determined at all times by observing the galvanometer deflections produced by determined resistance changes; third, that the galvanometer light spot may be slightly moved without using a control magnet."

In all the bolometric installations described in Volumes I, II, and III of the Annals, the tapes of the bolometer were in air at atmospheric pressure and generally without a glass or other plate in front to prevent currents of air from producing changes of temperature.

In the year 1902 [2] Lebedew showed the advantage of having radiation measuring instruments in a vacuum. The sensitiveness of the apparatus, according to him, may be increased several fold in that manner. When Dr. Abbot was in Berlin, in 1911, he called on Dr. Warburg at the Reichsanstalt and found him employing regularly a bolometer in vacuum. In Dr. Warburg's installation the apparatus was not perfectly air tight because it had certain stopcocks for convenience in manipulation and so required to be pumped out occasionally. However, the leakage was made almost insensible and the effects of it were counteracted by the use of charcoal cooled in liquid air.

After Dr. Abbot's return to Washington, with Mr. Aldrich he considered the possibility of substituting a vacuum bolometer for the ordinary installation for the solar-constant work, and their considerations led to the introduction of it on Mount Wilson in 1915. Later on an improved type of mounting was made for the bolometer in vacuum, so that the whole can be sealed up after evacuation, like an X-ray tube, and thereafter no further use of an air pump is necessary. This type was introduced in 1917 and is now used in Arizona and Chile.

At the same time Messrs. Abbot and Aldrich worked out the whole theory of the vacuum bolometer for solar and stellar work, considering the best length, breadth, thickness, and other peculiarities of the tapes, and how to obtain the optimum conditions of sensitiveness. The result of these investigations is given in what follows.

In our investigations of the sensitiveness of vacuum bolometers of different dimensions we were somewhat guided by the existing conditions of the apparatus at Mount Wilson, and for the proposed expedition to South America. The relative dimensions of the slit, the spectrometer room, and the image-forming mirror were such that the spectrum formed would be approximately 1.7 cm in height. We preferred to employ a bolometer tape slightly shorter than this in order that the spectrum might a little overlap its ends so that defects of the adjustment of the height of the beam might not lead to variations in the intensity of the rays falling on the bolometer tape. Thus we chose a total length of the tape of 1.6 cm, as

[2] Annalen der Physik 9. 1., 209–213, August, 1902.

used in the computations. We were also guided in the matter by the consideration of the probable necessary width of slit to be employed. Prior to the use of the vacuum bolometer the width of slit had been about 1.6 mm, which at the bolometer would correspond to a width of the image of the slit of about 0.25 mm. In bolometer practice it is desirable to have the width of the image of the slit approximately equal to the width of the bolometer tape. As we expected to gain something in sensitiveness by the use of the vacuum bolometer we therefore expected to employ slits of narrower width than those that had theretofore been used and accordingly we chose as the proper width for the bolometer tapes 0.10 mm as used in a large number of the computations.

Thus the matter resolved itself practically into determining the proper thickness of the vacuum bolometer tape whose length was 1.6 cm and whose width was 0.10 mm and to determine the proper electric current to be used with it. Our investigations solved these two questions satisfactorily to us.

THEORY OF THE VACUUM BOLOMETER

Let θ=the absolute temperature of the bolometer tape.
k=the thermal conductivity of the material.
$2l$=length of tape.
m=width of tape.
n=thickness of tape.
γ=electrical conductivity per cm^3 of the material.
x=distance from center of the tape to any point upon it.
σ=Stefan's constant of radiation.
i=electric current in the tape.
θ_1=absolute temperature at the point where $x=l$, that is to say, =the absolute temperature of the surroundings.

Let us assume the strip to be in vacuum, perfectly black on one face, perfectly reflecting on all others, so that the radiation from the black face and the conduction along the strip are the only means of cooling it.[3]

The problem is to determine the steady state of temperatures under the given current conditions subject to the boundary conditions as follows:

$$\frac{d\theta}{dx}=0 \text{ when } x=0, \quad \theta=\theta_1 \text{ when } x=l$$

Consider a section of the tape of length dx at the place x. It receives heat from the current, as follows: $\frac{0.24i^2}{\gamma mn}\,dx$

It loses heat by radiation as follows: $\sigma(\theta^4-\theta_1^4)m\,dx$

It gains heat by conduction as follows: $kmn\frac{d^2\theta}{dx^2}\,dx$.

[3] These assumptions approximate the facts. Solar rays received are almost fully absorbed by the lampblack paint on the front of the strip. Long-wave rays proper to the temperature are given out freely, though not perfectly by the lampblacked face. The unblacked surfaces, however, are highly reflecting for these long-wave rays and emit them but slightly.

Summing these terms, we find the following equation:

$$kmn\frac{d^2\theta}{dx^2}dx+\frac{0.24i^2}{\gamma mn}dx-\sigma(\theta^4-\theta_1^4)\,mdx=0$$

Whence:

$$\frac{d^2\theta}{dx^2}-\frac{\sigma\theta^4}{kn}+\frac{0.24i^2}{k\gamma m^2n^2}+\frac{\sigma\theta_1^4}{kn}=0$$

For simplicity, let

$$\frac{\sigma}{kn}=-A \text{ and } \frac{0.24i^2}{k\gamma m^2n^2}+\frac{\sigma\theta_1^4}{kn}=B$$

Then the equation becomes:

$$(1)\qquad \frac{d^2\theta}{dx^2}+A\theta^4+B=0$$

We have not been able to solve the equation generally, hence we make the assumption:

$$\theta=a+bx+cx^2+dx^3+ex^4+fx^5+gx^6+\cdots$$

Substituting this value of θ in equation (1), we have:

$$(2)\quad \theta=a-\frac{Aa^4+B}{2}x^2+\frac{a^3A\,(a^4A+B)}{6}x^4-\left[\frac{Aa^2}{20}(Aa^4+B)^2+\frac{A^2a^6}{45}(Aa^4+B)\right]x^6+\cdots$$

In equation (2) $\theta_0=a$ when $x=0$, and $\theta=\theta_1$ when $\theta=l$. Hence, by assuming values of θ_0 and θ_1 we are able to compute the distribution of θ along the tape for all values of x less than l corresponding to values of the length, breadth, and thickness of the bolometer tape suitable to solar work.

Putting $x=l$ in equation (2), we have:

$$(3)\quad a=\theta_1+\frac{l^2}{2}(Aa^4+B)-\frac{Aa^3l^4(Aa^4+B)}{6}+l^6\left[\frac{Aa^2}{20}(Aa^4+B)^2+\frac{A^2a^6}{45}(Aa^4+B)\right]+\cdots$$

From equations (2) and (3) and from the value of B already given, we obtain the differential coefficients as follows:

$$(4)\qquad \frac{da}{dB}=\frac{3l^2-Aa^3l^4}{6-12l^2\mathrm{Aa}^3+7l^4A^2a^6+3l^4ABa^2}$$

$$(5)\qquad \frac{d\theta}{dB}=\left[\left(1-2Aa^3x^2+\frac{7}{6}A^2a^6x^4+\frac{1}{2}Aa^2Bx^4\right)+\left(\frac{1}{6}Aa^3x^4-\frac{x^2}{2}\right)\right]\frac{da}{dB}$$

$$(6)\qquad \frac{dB}{di}=\frac{0.48i}{\gamma km^2n^2}$$

We may now use the information thus obtained in the following manner:

Assume values of θ_1 and θ_0, that is of the temperature of the surroundings and of the center of the bolometer tape, equal to a. From these values compute the value of B, and from this compute the corresponding value of i. Then corresponding to a certain fractional change in i, which we will call di, there are produced changes in B and changes in θ at the various values of x.

We have assumed tapes of fixed length, $2l=1.6$ cm, but of various widths and thickness, as well as of different materials, and we have taken the value of θ_1 at 290° absolute *C*. We have taken the value of $\theta_0=a$, either at 350° or 400°. With these various conditions we have computed from equation (3) the values of *B* and from these the values of θ corresponding to the different values of x, from $x=0$ to $x=l$, and then the changes on these values, corresponding to a change di, which for the first case we took $\frac{1}{100}$ part of i itself. In all subsequent cases we took such values of di that the change of energy occurring in the tape (corresponding to the change in the heat electrically produced, i^2r) should be the same as in the first case for which we took the value $di=\frac{1}{100}$ part of i.

Thus, as the reader will see, instead of employing a fixed quantity of radiation and determining the effect it will have upon the temperature of the vacuum bolometer strip, we have done what amounts to the same thing. For we have changed the quantity of the uniformly distributed electrical heating by a constant amount, by making a supposed increase in the current strength in the bolometer tape, and by determining the change of temperature occurring all along the tape corresponding to this constant change in the electrical energy introduced in it. Thus we are able to compare the efficiency of tapes of different dimensions and different materials under various conditions, such as would be possible in practice.

COMPUTATIONS.

We now give the results of nine different computations made according to this method as follows:

Case I.

$\theta_0=a=350°$ $\theta_1=290°$ Abs. C. Half-length $l=0.8$ cm.

Width=0.01 cm. Thickness=0.004 cm.

$B=\frac{0.24\, i^2}{k\gamma m^2n^2}+\frac{\sigma\theta_1^4}{kn}=461$ from equation (3)

Whence: $i=.0168$ amp.

In this computation it is permissible to neglect powers of x over x^4. We then find the following values corresponding to $di=0.01\ i$:

If $di=0.01\ i$, $di=0.000168$

x cm.	0.0	0.2	0.4	0.6	0.7	0.8
θ	° 350	° 346.8	° 336.8	° 318.6	° 305.8	° 290.0
$d\theta$	1.13°	1.05°	0.88°	0.55°	....	....

Whence mean $d\theta=0.78°$.

Case II.

$\theta_0=a=400°$. Other constants the same as in Case I, di being chosen to give the same change of heating energy as in the former case.

$\theta_0=a=400°$ $\theta_1=290°$ $l=0.8$ cm. $n=0.01$ cm. $n=0.0004$ cm. $\gamma=79\times10^3$ $k=0.17$ $B=775$ $i=0.0224$ amp. $di=0.000112$ amp.

x cm.	0.0	0.2	0.4	0.6
$d\theta$	0. 899°	0. 861°	0. 735°	0. 476°

Whence mean $d\theta=0.65°$.

Case III.

$\theta_0=a=320°$. Other constants the same. In this case we computed also the distribution of temperatures.

$\theta_0=320°$ $\theta_1=290°$ $B=264.5$. $i=0.0106$ amp. $di=0.000289$ amp.

x cm.	0.0	0.2	0.4	0.6
$d\theta$	1. 222	1. 153	0. 950	0. 578

Whence mean $d\theta=0.85°$.

Case IV.

With the same values of other constants as in Case I, the thickness of the strip, n, was altered to be 0.0002 in place of 0.0004, as in Case I. This led to the following results:

$n=0.0002$ cm. $a=350°$. $B=745$. $i=0.0101$ amp. $di=0.000142$ amp.

x cm.	0.0	0.2	0.4	0.6	0.8
θ	° 350	° 347. 3	° 340. 0	° 330. 6	° (290)
$d\theta$	1. 453	1. 393	1. 190	0. 767	(0)

Mean $d\theta=1.05°$.

Case V.

The values of all of the constants were as in Case I, excepting that n was taken as 0.0008 cm in place of 0.0004 cm, as in Case I. These conditions led to the following results:

$n=0.0008$ cm. $B=323.5$. $i=0.0299$ amp. $di=0.000191$ amp.

x cm	0.0	0.2	0.4	0.6	0.8
$d\theta$	0. 721°	0. 682°	0. 558°	0. 337°	(0)

Mean $d\theta=0.50°$.

Case VI.

A further change in n was made, taking $n=0.0012$ cm, in place of 0.0004 cm, as in Case I, other constants being as before. This led to the following results:

$n=0.0012$ cm. $B=277.3$. $i=0.0428$ amp. $di=0.000200$ amp.

x cm	0.0	0.2	0.4	0.6	0.8
$d\theta$	0.537°	0.506°	0.412°	0.269°	(0)

Mean $d\theta=0.37°$

Case VII.

In this computation we employed the constants proper to bismuth wire instead of platinum, and with circular cross section. In this case we suppose that one-half of the circumference is absolutely black and the other half polished. The constants were taken as follows, and these led to the following results:

$l=0.8$ cm. Radius, $\rho=0.005$ cm. $a=350°$. $\theta_1=290$. $\gamma=6\times10^3$. $\kappa=0.017$.
$B=405.2$ $i=0.0276$ amp. $di=0.000156$ amp.

x cm	0.0	0.2	0.4	0.6	0.8
$d\theta$	0.619°	0.587°	0.486°	0.301°	(0)

Whence mean $d\theta=0.43°$.

Case VIII.

Returning again to platinum as the material in this computation, we used round wire instead of flattened tape, with the following constants:

$l=0.8$ cm. Radius$=0.0025$ cm. $a=350°$. $\theta_1=290°$. $\gamma=78\times10^3$. $k=0.17$.
$B=230.5$. $i=0.0665$ amp. $di=0.000211$ amp.

These conditions led to the following results:

x cm	0.0	0.2	0.4	0.6	0.8
$d\theta$	0.371°	0.349°	0.282°	0.166°	(0)

Mean $d\theta=0.25°$.

Case IX.

We now consider the platinum of radius as in Case VIII to be flattened so that its width m equals 0.012 cm, its thickness n equals 0.0017 cm. With this and the other constants of platinum wire we derive the following results:

$m=0.012$ cm. $n=0.0017$ cm. $B=251.1$. $i=0.0707$ amp. $di=0.000206$ amp.

x cm	0.0	0.2	0.4	0.6	0.8
θ	350°	346.4°	335.4°	316.8°	(290)°
$d\theta$	0.338	0.318	0.258	0.161	(0)

Whence mean $d\theta=0.225°$.

The foregoing results may be amplified by the reader to suit other values of the bolometer width m, for since the expression for θ depends only on a, A, and B, all tapes for which these quantities are constant will have equal distribution of temperatures. The value of a we may take as a constant for all cases; the value of A is unchanged if we retain the same chemical constitution and thickness for the tape; the value of B is unchanged if in addition we retain the temperature of the surroundings constant and vary the width of tape and strength of current proportionally so that $\frac{i}{mn}$ is constant. Accordingly, the results of the computations as just given are applicable to other tapes of other widths, provided only the current strength and the width are varied proportionally.

Referring to the preceding computations of the rise of temperature of the bolometer tape when heated by equal increments of energy, lineally applied over the whole length of the tapes, further steps were made by taking for each case the double resistance of the strip as computed by the formula $2R=\frac{4l}{\gamma mn}$. Referring to these Annals, Volume I, page 246, equation (4), for the case of balancing coils of resistances large as compared with the resistance of the bolometer tapes, g, the current flowing in the coils of a galvanometer connected to the bolometric apparatus varies approximately as follows:

$$g \propto \frac{i \times \text{mean } d\theta}{2R+G}$$

The galvanometer deflection obtained will be approximately proportional to the current g, and to the square root of the galvanometer resistance G. That is,

$$\Delta \propto g\sqrt{G}$$

The maximum deflection will, however, occur with the best resistance of the galvanometer. which for this case is

$$G=2R\frac{N}{N+1}$$

where N is the ratio of resistance of the balancing coil to the bolometer tape. Taking $N=10$, $G=1.8R$.

Computations summarized.—We now summarize the results of the various computations. In all cases $l=0.8$ cm, $m=0.01$ cm excepting in Cases VIII and IX, and in all cases the material used is platinum, except in Case VII, when bismuth was employed. The temperature of the surroundings, θ_1, was taken as 290° Abs. Centigrade in all cases. The temperature at the middle of the strip, θ_0, being also chosen, these conditions fixed for each computation the value of the quantity B as determined by equation (3). This in turn fixed the value of i. A change of i, di, was then chosen so as to give equal increments of heat energy to each tape examined. The corresponding increments of θ along the tape were therefrom computed. From the value of i and mean $d\theta$, values proportional to the deflection of a galvanometer of chosen resistance connected to a Wheatstone's bridge of which the investigated vacuum bolometer tape formed a part were then obtained.

TABLE 1.—*Summary of computations for solar vacuum bolometer.*

Case	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
							(Bismuth.)		
i amp	0.0169	0.0224	0.0106	0.01006	0.0299	0.0428	0.0276	0.0665	0.0707
di amp	.000169	.000112	.000289	.000142	.000191	.000200	.000156	.000211	.000206
n cm	.0004	.0004	.0004	.0002	.0008	.0012	Radius ρ=.005 (Circular).	Radius ρ=.0025 (Circular).	m=.012 n=.0017
$a=\theta_0$	350°	400°	320°	350°	350°	350°	350°	350°	350°
Mean $d\theta$	0.78°	0.65°	0.85°	1.05°	0.50°	0.37°	0.43°	0.25°	0.225°
$2R$ ohms	10.25	11.77	9.53	20.50	5.13	3.42	6.78	2.09	2.01
$10^3 g\sqrt{G}$ for G:									
=3 ohms	1.72	1.71	1.25	0.78	3.19	*4.28*	*2.6	†5.68	‡5.46
=5 ohms	1.94	1.94	1.39	0.93	*3.30*	....	....	....	....
=10 ohms	*2.06*	*2.12*	*1.46*	1.11	3.12	....	....	....	....
=20 ohms	1.95	2.05	1.36	*1.17*	2.66	....	....	....	....

* As the coefficient of resistance change for bismuth is $\frac{47}{36}$ times that for platinum this value becomes 2.9.

† As this round wire is but half the width of the tapes used previously it could receive but half as much radiation. Hence in an identical optical system its corresponding deflection value would be 2.84.

‡ As this tape is wider than the others we may increase the value to 6.55 for reasons set forth in note (†).

From these results it appears for vacuum bolometers of length $2l$=1.6 cm:

1. There is but a small gain in increasing the temperature of the bolometer to 400° instead of 350° by stronger battery current. In other words, with a battery current strong enough to raise the temperature of the vacuum bolometer tape 60° above the temperature of its surroundings, the sensitiveness is almost as great as with a battery current sufficient to raise the temperature 110°. Compare Cases I, II, III.

2. With the best galvanometei resistance the heavier tapes give the larger deflections.

3. For equal widths of tape there is not a very great gain, however. Compare Case IX, for a very coarse tape, with Cases V and VI. But for tapes of smaller cross section than V the loss is almost too great to be admitted.

4. There is no justifying gain in using bismuth or iron in preference to platinum.

5. The substantial equivalence of Cases VIII and IX, where equal increments of energy are introduced, shows that tapes of round cross section are equal to the same tapes flattened, or are indeed slightly superior. That is to say, if the tape VIII was used with $\frac{5}{12}$ the focal length of image forming mirror that is used with tape IX, it would give fully equal deflections to tape IX and with equal purity of spectrum. In this way great sensitiveness could go with great purity of spectrum. For example, in our work of the year 1896, where a very thin bolometer tape of 0.002 cm width was used, an equally wide bolometer tape of circular cross section could have been used and would have been far more sensitive if in vacuum.

The tape employed in the computation of Case IX gave somewhat greater sensitiveness than any of the others. We therefore constructed a vacuum bolometer of such characteristics and introduced it on Mount Wilson in September, 1915. But it proved a little sluggish in response, though very sensitive. Considering that nearly as favorable results were obtained in Cases V and VI with much thinner tapes which would undoubtedly come to a steady state of temperatures much quicker than the heavy tape used in Case IX, no question could be left in our minds that something near the size employed in Cases V and VI would be more suitable. New vacuum bolometers of nearly such general dimensions and described below are now in use in Arizona and Chile.

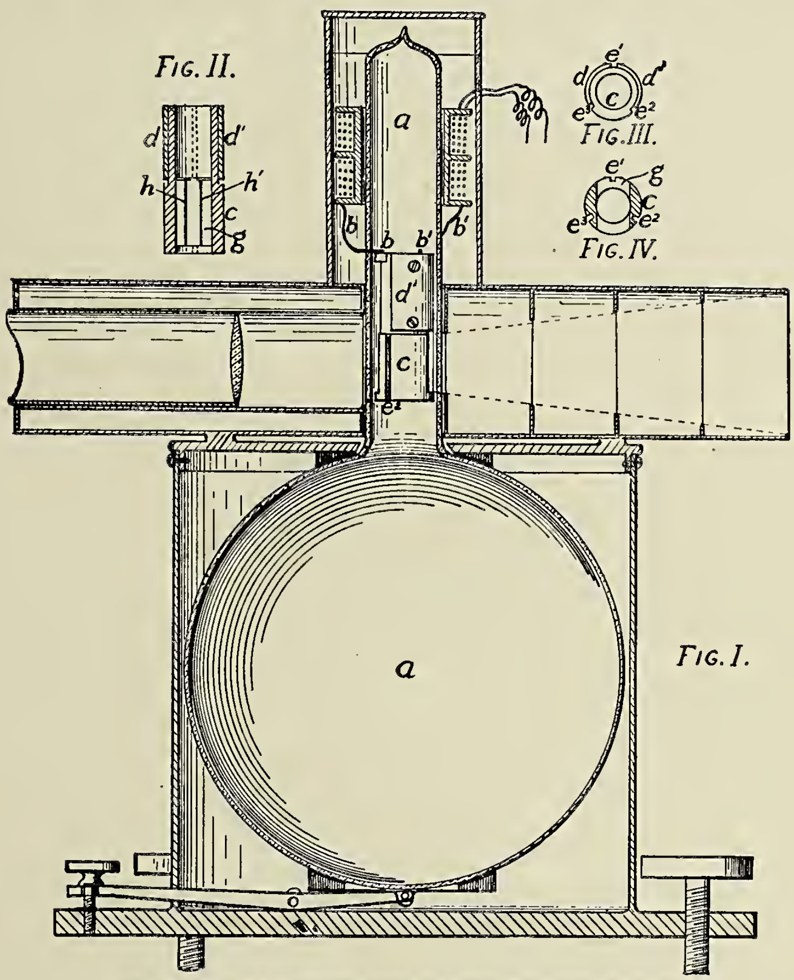
CONSTRUCTION OF VACUUM BOLOMETER.

In carrying into effect the results of the investigations, we constructed the bolometric apparatus as indicated in the accompanying diagram. Figure 1 shows the vacuum flask within the brass case, shown in section. Figure 2 is a longitudinal cross section of the bolometer frame. Figure 3 is the end view of the bolometer frame looking from above. Figure 4 is a cross-sectional view near the bottom of it looking from above. *a* is a glass flask of excellent material whose neck is as free from striae and defects of bubbles and the like as it was possible to find. At *b* were introduced three platinum wires (one not shown in the figure) to make electrical connection with the interior. A copper piece *c* was constructed having upon it the two electrically insulated pieces d, d^1, and having slots e^1, e^2, e^3 to allow the piece to be shoved down the neck of the flask *a*, past the platinum wires *b*. The piece *c* had both a longitudinal round hole and a transverse rectangular hole *g*, sixteen millimeters by ten millimeters. The two bolometer tapes were arranged to be soldered across the rectangular hole *g* so as to expose lengths of 16 mm each. The upper end of the bolometer tapes were attached to the insulated pieces d, d^1. Thus when the whole copper piece *c* was slid into the neck of the flask *a*, past the platinum wires *b*, it could be rotated slightly so that these wires, b^1, b^2, b^3, could be soldered to the piece *c* as a whole and to the two insulated parts of it, d, d^1, and so be in proper connection with the two bolometer tapes h, h^1.

The bolometer tapes h, h^1, were prepared from platinum wire which we had in stock of one one-thousandth inch in diameter. This was hammered out between steel flats to a width of 0.12 mm. The resistances of the tapes for the Chile bolometer were found to be, respectively, 2.98 and 3 ohms. Outside of the flask *a* was placed a spool of wood having wound upon it two coils of manganin wire of 54 and 54.3 ohms, respectively. The system was found to be balanced when a shunt of 7,000 ohms was connected round the coil of 54 ohms resistance.

The neck of the glass flask *a* was drawn down after all was inserted within it and sealed off after having been evacuated and warmed repeatedly for several days with drying material in close proximity. The vacuum reached was as high as it was possible to obtain with a mercury pump of the Gaede pattern, and was surely beyond one ten-thousandth millimeter.

The whole instrument as mounted in the supporting case as shown in the accompanying figure has provision for examining the spectrum by means of an eyepiece. The spectrum is admitted, with screens against stray light, through an appropriate vestibule. The apparatus so constructed was first employed at Hump Mountain, North Carolina, and later on the South American expedition of the



Figs. 1, 2, 3, and 4.—Sectional view and details of vacuum bolometer.

Smithsonian Institution, but it proved so successful that a similar piece of apparatus was constructed with almost identical constants and has been in use at Mount Wilson since July 15, 1917. It was removed to Arizona in September, 1920. These bolometeis are suited to the use of a battery current of 0.07 ampere which is caused to divide, half going through one tape, half through the other, so that the actual current in the several tapes is 0.035 ampere. We compute that this should raise the temperature of the tapes over the temperature of the surroundings by about 50° or 60° C.

TESTS.

We were naturally much interested to know, both theoretically and practically, how much superior the vacuum bolometer is to the bolometer in air which we had hitherto used at Mount Wilson. In order to make this comparison we were obliged to discuss also the theory of the bolometer in air.

For a rough estimate we judged it unnecessary to employ the fourth power radiation formula in this new computation because if the difference of temperature between the tape and its surroundings does not exceed 100° the cooling of the tape in air depends mainly on convection, which for such moderate difference of temperature and for thin and narrow tapes is several-fold greater than the loss of heat to the surroundings due to radiation. Accordingly, we employed Newton's law of cooling, and this led to a differential equation which follows:

Let the quantities k, m, n, l, γ, i, di, have the same significance as in the preceding work, and let ϵ be the average emissivity, taking into account both the black and bright sides of the bolometer tape. Let θ be the excess of temperature of the tape over the surroundings.

For a section of the tape distant x from the center and of length dx, we have the following conditions:

Tape gains heat by conduction: $kmn\frac{d^2\theta}{dx^2}dx$

Tape gains heat from electric current: $\frac{0.24i^2}{\gamma mn}dx$

Tape loses heat by emissivity: $2\epsilon m\theta dx$

In this last expression we use the factor 2, taking into account both the black and the bright sides but neglecting the edges, for the thickness is negligible compared with the width of the tape.

Hence we have:

(1) $$kmn\frac{d^2\theta}{dx^2}dx+\frac{0.24i^2}{\gamma mn}dx-2\epsilon m\theta dx=0$$

Or

(2) $$\frac{d^2\theta}{dx^2}-\frac{2\epsilon\theta}{kn}+\frac{0.24i^2}{k\gamma m^2n^2}=0$$

Subject to the conditions:

$$\theta=0 \text{ when } x=l;\text{ and } \frac{d\theta}{dx}=0,\text{ when } x=0.$$

Whence:

(3) $$\theta=\frac{0\cdot 12i^2}{\epsilon\gamma m^2n}\left(1-\frac{e^{x\sqrt{2\epsilon/kn}}+e^{-x\sqrt{2\epsilon/kn}}}{e^{l\sqrt{2\epsilon/kn}}+e^{-l\sqrt{2\epsilon/kn}}}\right)$$

Or

(4) $$\theta=\frac{0\cdot 12i^2}{\epsilon\gamma m^2n}\left(1-\frac{\cosh x\sqrt{2\epsilon/kn}}{\cosh l\sqrt{2\epsilon/kn}}\right)$$

And:

(5) $$\frac{d\theta}{di}=\frac{0\cdot 24i}{\epsilon\gamma m^2n}\left(1-\frac{\cosh x\sqrt{2\epsilon/kn}}{\cosh l\sqrt{2\epsilon/kn}}\right)$$

We formerly employed at Mount Wilson and in Algeria a bolometer in air whose tapes were of length 1.2 cm, width 0.01 cm, thickness 0.00043 cm, resistance 3.4 ohms. As its material was platinum, the quantities γ and k have the same numerical values as in the earlier computations. As to ϵ, the emissivity, there is some doubt. Referring to Smithsonian Physical Tables, sixth revised edition, pages 252 and 253, it appears that for spheres of some considerable dimensions the value of ϵ for a polished surface is of the order 0.00023 and for a blackened surface 0.00033, for a difference of temperature of the order of 60°, such as we are concerned with. But according to Bottomley's results for the cooling of fine platinum wires within a copper envelope, much larger values of the emissivity ought to be employed. His results would indicate a value of ϵ of about 0.002, but unfortunately relate to a temperature difference of 408° C.

We ourselves have made some rough experiments which indicate that the cooling by convection of thin tapes is several times more rapid than the corresponding cooling of the surfaces of large bodies for equal areas. Accordingly we think we may very properly assume that the value of ϵ is not likely to be less than 0.001, and may be as great as 0.0015. We have carried through the computations with both these values.

When $\epsilon=0.001$:

$x=$	0 cm	0.2 cm	0.4 cm	0.5 cm	0.55 cm	0.6 cm
$\theta=$	117°	111°	81°	49°	25°	0°
$d\theta=$	0.207°	0.195°	0.144°	0.087°	0.045°	0.00°

Mean $d\theta=0.15°$

When $\epsilon=0.0015$:

$x=$	0 cm	0.2 cm	0.4 cm	0.5 cm	0.55 cm	0.6 cm
$\theta=$	82°	79°	62°	41°	24°	0°
$d\theta=$	0.145°	0.139°	0.109°	0.072°	0.042°	0°

Mean $d\theta= 0.10°$

Computing the values of the function $\left\{\frac{i\ (\text{mean}\ d\theta)}{2R+G}\right\}\sqrt{G}$ for the case $G=5$ ohms, $2R=6.84$ so as to compare with values already given for vacuum bolometers, we find, when $\epsilon=0.0010$, function$=0.70\times10^{-3}$, and when $\epsilon=0.0015$, function$=0.50\times10^{-3}$. Considering Cases V and VI given in the tables, the function came out 3.3 and 4.3×10^{-3}, respectively, and we should therefore expect that our newly constructed vacuum bolometer 1.6 cm long, 0.12 cm wide, and about 0.0007 cm thick, would give between five and ten times as much deflection in the same solar spectrum as the bolometer in air formerly employed at Mount Wilson and Bassour. Our vacuum bolometer used in 1916 on Mount Wilson was similar to that listed in Case IX. For this the function is 6.55×10^{-3}, so that we ought to expect with it between ten and twenty times the deflection given by the bolometer in air if exposed in the same spectrum.

On September 17, 1915, the following trial was made of the vacuum bolometer similar to Case IX.

Pressure of air 0.0005 mm mercury; current in bolometer tape 0.07 ampere; usual time of swing of galvanometer.

The two bolometers, one in air and one in vacuum, were so arranged that the solar spectrum could be moved easily from one to the other. Adjustments were made upon the A line in the red of the spectrum, so that the setting of the clock-work in each case was at 200:00. Setting at the position 195:10 in the spectrum corresponding to a position in the green, the bolometer in air gave 1.2 cm deflection of the galvanometer with the third rotating sector in front of the slit. The vacuum bolometer under the same circumstances gave 14 cm deflection, or twelve times as much as the bolometer in air.

The relative sensitiveness of the newer vacuum bolometer and the bolometer in air also falls within the limits of expectation. Thus in Algeria we employed a slit width of about 2 mm with the bolometer in air, but in North Carolina only 0.35 mm with the vacuum bolometer. Otherwise the arrangements employed were exactly the same, except that in North Carolina a coelostat of two silvered mirrors was interposed in the beam, while in Algeria the apparatus was pointed directly at the sun without the intervention of mirrors. Neglecting this difference which is in favor of the vacuum bolometer, the relative sensitiveness of the two would be about sixfold. This, however, does not take into account that the sensitiveness of the bolometer as used in North Carolina was intentionally diminished by diminishing the battery current somewhat so as not to use too narrow a slit. The amount of resistance in series with the bolometer was different at different times but had an effect of the order of $1\frac{1}{2}$ fold so that we may say that roughly speaking the sensitiveness of the vacuum bolometer used in North Carolina was about ten times as great as that of the bolometer in air used in Algeria.

A more accurate determination was made of the relative sensitiveness of the bolometer in air used in Algeria and the vacuum bolometer used on Mount Wilson. It is as follows:

Mount Wilson, June 27, 1919, Mr. Aldrich employed the new vacuum bolometer alternately with the Algerian bolometer, shifting the image-forming mirror of the spectroscope so as to throw the spectrum alternately from one bolometer to the other as they were placed side by side. The vacuum bolometer was employed with the usual current of 0.07 ampere and the Algerian bolometer with a current of 0.10 ampere in the outside circuit. The galvanometer sensitiveness, width of slit and everything else was exactly similar for each test. With these arrangements Mr. Aldrich took bolographs of the solar spectrum with each bolometer successively. The ordinates of the bolograph taken with the vacuum bolometer averaged more than eight times[4] as great as those of the bolograph taken with the Algerian bolometer in these circumstances. Height of the spectrum at the bolometer was 17 mm; length of the strip of the Algerian bolometer 12 mm; length of the strip of the new vacuum bolometer, 16 mm.

On the whole, then, we may say that the theoretical and experimental results obtained in the investigation of vacuum bolometers for solar work are in good agreement and that nearly tenfold increase of sensitiveness under similar conditions of spectrum was obtained.

ON THE THEORY OF A VACUUM BOLOMETER FOR USE IN DETERMINING THE DISTRIBUTION OF ENERGY IN STELLAR SPECTRA.[5]

When the great hundred-inch telescope of the Mount Wilson Solar Observatory was being made, Director George E. Hale suggested to Mr. Abbot the advantage of measuring the relative intensity of focal images and the distribution of energy in the spectra of the brighter stars, and inquired of him whether he considered that a bolometer or a radiometer or thermopile such as had been used by Messrs. Pfund, Coblentz, and others would be most suitable. Mr. Abbot gave the matter some attention based upon the known performance of the bolometer in solar work upon Mount Wilson and concluded that at least as high sensitiveness could be obtained with the bolometer as with other radiation instruments, and with special advantages of form for spectrum observations.

The probable result was estimated as follows: The solar beam reflected from the two-mirror coelostat passed through a slit 10 cm high, 0.15 cm wide, of total area 1.5 cm^2; thence upon a 60° ultra-violet crown-glass prism to a concave mirror, this bringing the solar spectrum from the 10 cm high slit to a focus about 1.7 cm high, where it fell upon a bolometer in air at that time about 1.2 cm high and 0.08 cm wide. The heating of the bolometer was observed by means of a galvanometer in air, having a time of single swing 1.8 seconds and giving a deflection in the hotter part of the solar spectrum of about 10 cm. This deflection was obtained when a rotating sector cutting down the intensity of the solar beam thirtyfold was employed in front of the slit. Comparing this state of affairs with that which would prevail in observing a stellar spectrum with the 100-inch telescope, we have the following: Relative areas of light collectors 50,000 to 1.5; a loss at the slit jaws of the stellar spectroscope estimated 0.40 is balanced by a loss at the bolometer of the solar spectroscope estimated the same; linear dispersion of stellar spectroscope, estimated 0.1 that of solar spectroscope, factor 10; sector removed, factor 30; deflection of the galvanometer reduced to 1 cm, factor 10; greater sensitiveness of vacuum bolometer, factor estimated at 10; greater sensi-

[4] See under a later caption, "Distribution of Energy in the Solar Spectrum," a curious fact found in this comparison.
[5] This section does not relate to solar work, but is given here because it follows so closely from what precedes.

tiveness of stellar galvanometer in vacuum, factor 100. Under these circumstances the factor in favor of the stellar spectroscope becomes 1×10^{11}, corresponding to over 27.5 stellar magnitudes. As the sun's stellar magnitude is −26.5 the conclusion is that the spectrum of stars of the first magnitude may be observed by the bolometer under these circumstnaces with a deflection at the hotter part of the energy curve of 1 cm.

The comparison is hardly as favorable as might be made, for by special design of the stellar bolometer it ought certainly to be more suitable for stellar work than a solar vacuum bolometer 16 mm long, which, as already stated, gave a factor of about 10. Furthermore, by placing the galvanometer in vacuum, raising the time of single swing to at least 5 seconds, lengthening the scale distance to at least 4 m in place of 1 m, and by employing a 2-coil galvanometer in magnetic shielding instead of the 16-coil galvanometer then employed at Mount Wilson, the factor for the galvanometer as thus improved ought to be nearer 1,000 than 100. Furthermore, it would evidently be possible to get a very good idea of a stellar energy spectrum whose maximum ordinate was less than 1 cm—even as small as 0.3. Thus it might well be hoped that good indications of the form of the energy spectra of the stars as faint as the fourth or even fifth magnitude might be secured.

Mr. Hale thereupon suggested to Mr. Abbot the preparation of apparatus for observing the energy of the stellar images and spectra for use with the 100-inch telescope when it should be completed. In connection with this project the following investigation of the proper dimensions and conditions of use of a bolometer for this purpose was made. The investigation is based upon the determination of proper dimensions of the vacuum bolometer for solar work just given, but certain changes had to be made in view of the different distribution of the rays from the very narrow stellar spectrum as compared with the rays from the much wider solar spectrum.

According to previous work, described at an earlier page, on the proper dimensions of the vacuum bolometer for solar spectrum work, the steady state of temperature distribution along a wire carrying a current is found to be in vacuum

$$(1) \qquad \theta=a-\frac{Aa^4+B}{2}x^2+\frac{Aa^3(Aa^4+B)}{6}x^4+\ \dots$$

The quantities A, B, a, θ were defined at an earlier page.

We assume the tape to be absolutely black on one side and absolutely reflecting on the other, and so thin compared with its width that the radiation from the edges can be neglected.

Suppose the stellar radiation to fall upon the center of the tape over a length 2λ, and let us assume $\lambda=0.05$ cm, corresponding to a diameter of the stellar image of $\frac{1}{10}$ cm in the focus of the great telescope. Let us suppose further that the superposition of this stellar radiation upon the bolometer tape already heated to the temperatures θ as defined in equation (1) produces finally a rise of temperature equal to τ at any point upon the tape, τ being very small compared to θ.

COMPUTATIONS.

Two cases now arise.

Case I.—For an element of tape of length dx at points where $x > \lambda$. For such an area the loss of stellar heat by radiation is equal to $4\ \sigma\theta^3\tau m dx$.

The gain of stellar heat by conduction is equal to $kmn\frac{d^2\tau}{dx^2}dx$.

Hence:

$$\frac{d^2\tau}{dx^2}=\frac{4\sigma}{kn}\theta^3\tau. \tag{2}$$

Case II.—For a similar element dx, where $x < \lambda$, the gain of stellar heat by radiation$=qmdx$.

Hence:

$$\frac{d^2\tau}{dx^2}-\frac{4\sigma}{kn}\theta^3\tau=\frac{q}{kn}. \tag{3}$$

In both equations the quantities employed are the same as those employed in the investigation of the solar vacuum bolometer with the addition of the quantity τ, which has been already described, and the quantity q, which indicates the intensity of stellar radiation in the focal image or stellar spectrum of the great telescope.

Consider further case (1).

Assume $\tau=D+Ex+Fx^2+Gx^3+Hx^4+Ix^5+Jx^6$.

Substituting this value of τ in equation (2) and for θ^3, the value obtained by cubing the equation for θ as given above, and proceeding similarly with equation (3), we obtain two long expressions whose constants are to be evaluated by the theorem of undetermined coefficients, and by applying to the results the following boundary conditions:

When $x=l$, $\tau=0$;

When $x=\lambda$, $\tau=\tau_\lambda$;

When $x=0$, $\frac{d\tau}{dx}=0$;

When $x=\lambda$, $\tau_\lambda=\tau^1{}_\lambda$.

Performing these operations and omitting terms which are evidently negligible and substituting the values in the original equation, we obtain for Case I, when $x > \lambda$.

$$\tau^1=\frac{q\lambda}{kn}\left(S-x+gSx^2-\frac{g}{3}x^3+\frac{g(ga^3-M)}{6a^3}Sx^4\right) \tag{4}$$

For Case II, when $x < \lambda$, we have:

$$\tau=\frac{q\lambda}{kn}\left\{\left(S-\frac{\lambda}{2}\right)+\left[g\left(S-\frac{\lambda}{2}\right)-\frac{1}{2\lambda}\right]x^2\right\} \tag{5}$$

In these expressions, $g=\frac{2\sigma a^3}{kn}$, $M=\frac{3}{2}a^2(Aa^4+B)$ and

$$S=\frac{l+\frac{gl^3}{3}+\frac{gl^5}{10a^3}\left(\frac{ga^3}{3}-M\right)}{1+gl^2+\frac{gl^4}{6a^3}\left(ga^3-M\right)}$$

Having these results, of which the first gives the distribution of temperatures for values of $x>\lambda$, and the second gives the distribution of temperatures for values of $x<\lambda$, we now go on to substitute various values of l, as follows: 0.8, 0.5, 0.4, 0.3, 0.2 cm, and of m, 0.012, 0.010, and 0.005, and of n, 0.0017, 0.0008, 0.0004, 0.0002, 0.0001, and 0.00005. These values of the quantities l, m, and n are employed along with values of x such as to divide the length l into equal parts.

Illustrative examples.—In illustration of these computations we give the following numerical data. All are based on those of the solar vacuum bolometer computations previously made, for which $\theta_0=350°$ and $\theta_1=290°$. The arbitrary values of $10^5\tau$ depend on the assumption $q=10^{-6}$.

TABLE 2.—*Illustrative examples of stellar vacuum bolometers.*

l.	*m.*	*n.*	$10^5\ \tau$ (arbitrary units) when x is—									
			0	λ	0.1	0.15	0.2	0.3	0.4	0.5	0.6	0.8
0. 2	0. 012	0. 0017	2. 98	2. 56	1. 70	0. 77	00	......	......	......	......	......
		.0008	6. 28	5. 38	3. 57	1. 78	00	......	......	......	......	......
		. 0004	12. 26	10. 47	6. 94	3. 44	00	......	......	......	......	......
		. 0002	23. 4	19. 93	13. 12	6. 47	00	......	......	......	......	......
		. 0001	42. 8	36. 25	23. 6	11. 5	00	......	......	......	......	......
		. 00005	73. 3	61. 1	38. 63	18. 0	00	......	......	......	......	......
0. 3	0. 010	0. 0017	4. 63	4. 21	3. 34	......	1. 67	00	......	......	......	......
		0. 0008	9. 6	8. 7	6. 9	......	3. 43	00	......	......	......	......
		. 0004	18. 3	16. 5	13. 07	......	6. 41	00	......	......	......	......
		. 0002	33. 5	29. 96	23. 45	......	11. 28	00	......	......	......	......
		. 0001	56. 8	50. 3	38. 4	......	17. 8	00	......	......	......	......
		. 00005	88. 9	77. 2	56. 5	......	24. 9	00	......	......	......	......
0. 4	0. 012	0. 0017	6. 48	6. 06	5. 22	......	3. 55	1. 91	00	......	......	......
		. 0008	12. 6	11. 7	9. 97	......	6. 56	3. 26	00	......	......	......
		. 0004	23. 5	21. 7	18. 3	......	12. 0	5. 97	00	......	......	......
		. 0002	40. 4	37. 1	30. 8	......	20. 8	9. 18	00	......	......	......
		. 0001	64. 3	58. 2	46. 7	......	27. 9	12. 66	00	......	......	......
		. 00005	95. 3	83. 8	64. 0	......	36. 1	20. 9	00	......	......	......
0. 5	0. 010	0. 0002	45. 1	41. 7	35. 5	......	24. 7	15. 53	7. 12	00	......	......
		. 0001	68. 5	61. 6	50. 9	......	33. 35	20. 3	10. 58	00	......	......
0. 8	0. 12	0. 0017	11. 46	11. 16	......	......	8. 62	......	5. 78	......	2. 76	00
		. 0008	21. 16	20. 26	......	......	15. 38	......	9. 74	......	4. 56	00
		. 0004	34. 16	32. 46	......	......	23. 40	......	14. 06	......	6. 48	00
		. 0002	49. 90	48. 34	......	......	32. 00	......	18. 12	......	8. 80	00

As was stated in reference to the solar vacuum bolometer computations, the distribution of temperatures is identical in all tapes of equal length and thickness provided the ratio $\frac{i}{mn}$ is kept constant. We have used this consideration to amplify our results without additional computations.

In order to determine the relative sensitiveness of the different vacuum bolometer tapes for which these computations were made, we require to know the change of galvanometer current, *dg*, corresponding to the superposition of the radiation of the stellar focal image or of the stellar spectrum examined. This current, *dg*, is proportional to *i*, the current in the tape, also to the mean value of τ along it and to $\sqrt{G}$ where G is the resistance of the galvanometer. According to these Annals, Volume I, page 246, as already stated at an early page of the present volume, the most favorable arrangement of the bolometer occurs when the resistance coils of its Wheatstone's bridge are large compared with the resistance of the bolometer tape. Assuming the corresponding resistance factor to be 10, the most favorable value of the galvanometer resistance, G is equal to 1.8 times the resistance of the bolometer tape. We have made computations on this basis. The current, i, in the bolometer tape is determined from the equation $B=\frac{0.24i^2}{k\gamma m^2n^2}\ \frac{\sigma}{kn}\ \theta_1^4$, which has been given at an earlier page.

Computations summarized.—A summary of the values of i, mean τ and $\sqrt{G}$, along with their relation to l, m, and n, is given below.

TABLE 3.—*Results of computations on vacuum bolometers for stellar spectra.*

l.	m.	n.	R.	$R\times1.8=G$.	i (amp.).	Mean τ.	$i\times\sqrt{G}\times$mean τ.
0.2	0.005	0.0017	0.564	1.016	0.1102	1.60×10^{-5}	0.1779×10^{-5}
		.0008	1.200	2.16	.0522	3.35	.2575
		.0004	2.400	4.32	.02473	6.60	.340
		.0002	4.8	8.64	.01342	12.60	.498
		.0001	9.6	17.28	.00697	23.0	.667
		.00005	19.2	34.56	.00374	37.5	.825
.2	.010	.0017	.282	.507	.2205	1.60×10^{-5}	$.2514\times10^{-5}$
		.0008	.600	1.08	.1044	3.35	.3645
		.0004	1.200	2.16	.0495	6.60	.480
		.0002	2.4	4.32	.02684	12.60	.703
		.0001	4.8	8.64	.01394	23.0	.944
		.00005	9.6	17.28	.00758	37.5	1.183
.2	.012	.0017	.235	.423	.265	1.60×10^{-5}	$.276\times10^{-5}$
		.0008	.50	.90	.1252	3.35	.398
		.0004	1.00	1.80	.0592	6.60	.525
		.0002	2.00	3.60	.0322	12.60	.770
		.0001	4.00	7.20	.01651	23.0	1.022
		.00005	8.00	14.40	.00897	37.5	1.278

TABLE 3.—*Results of computations on vacuum bolometers for stellar spectra*—Continued.

l.	m.	n.	R.	$R\times1.8=G$.	i (amp.).	Mean r.	$i\times\sqrt{G}\times$mean r.
0.3	0.010	0.0017	0.432	0.762	0.148	2.45×10^{-5}	0.317×10^{-5}
		.0008	.900	1.62	.0703	5.1	.457
		.0004	1.800	3.24	.03595	9.75	.632
		.0002	3.600	6.48	.0187	17.4	.830
		.0001	7.2	12.96	.01013	29.0	1.057
		.00005	14.4	25.92	.00575	45.4	1.33
.4	.005	.0017	1.13	2.035	.0559	3.40×10^{-5}	$.272\times10^{-5}$
		.0008	2.4	4.32	.0268	6.40	.357
		.0004	4.8	8.64	.0139	12.0	.491
		.0002	9.6	17.28	.00748	20.8	.647
		.0001	19.2	34.56	.0042	32.0	.791
		.00005	38.4	69.12	.00251	45.0	.940
.4	.010	.0017	.564	1.016	.1116	3.40×10^{-5}	$.382\times10^{-5}$
		.0008	1.20	2.16	.0537	6.40	.505
		.0004	2.40	4.32	.0279	12.0	.697
		.0002	4.80	8.64	.01496	20.8	.917
		.0001	9.60	17.28	.0084	32.0	1.119
		.00005	19.2	34.56	.00503	45.0	1.333
.4	.012	.0017	.470	.846	.134	3.40×10^{-5}	$.419\times10^{-5}$
		.0008	1.000	1.80	.0644	6.40	.555
		.0004	2.00	3.60	.0334	12.0	.761
		.0002	4.00	7.20	.0179	20.8	1.000
		.0001	8.00	14.40	.01011	32.0	1.230
		.00005	16.00	28.80	.00604	45.0	1.460
.5	.010	.0002	6.0	10.8	.0128	21.7×10^{-5}	$.913\times10^{-5}$
		.0001	12.0	21.6	.00759	30.5	1.063
.8	.010	.0002	9.6	17.3	.0101	12.5×10^{-5}	$.526\times10^{-5}$
		.0001	19.2	34.6			
.8	.012	.0017	.941	1.693	.0709	2.94×10^{-5}	$.271\times10^{-5}$
		.0008	2.000	3.60	.0359	5.24	.358
		.0004	4.00	7.20	.0201	8.47	.458
		.0002	8.00	14.40	.0121	12.5	.575

Inspection of the results shows, contrary to the conclusions arrived at in determining the best dimensions for a solar vacuum bolometer, that the most effective stellar vacuum bolometer must be exceedingly thin, and consequently of high resistance. The best result found in the table is gained with tapes of 0.8 cm total length, 0.012 cm wide, and 0.00005 cm thick. Such tapes have 16 ohms resistance, and require only 0.012 ampere external battery current for the bolometer bridge. They would appear to be more than five times as sensitive for stellar work as the solar vacuum bolometer now in use on Mount Wilson would be, and more than fifty times as sensitive for this work as the bolometer in air used at the time the preliminary computations were made would be.

2. THE PYRANOMETER.

There has lately come into use in our solar observations an instrument which we call the pyranometer. The purpose of this instrument is to determine the intensity of the radiation from the sky. It may be employed either as a horizontal surface or mounted equatorially so as to present a surface at right angles to the solar beam. The cone of rays observed may be limited by diaphragms to any desired angle less than a hemisphere or may be arranged to include the whole hemisphere of the sky light. We employ the pyranometer not only for investigations of sky light, but in connection with the spectrobolometer and pyrheliometer to determine the solar constant of radiation by a new empirical method which appears to be of quite as high accuracy as the method hitherto employed and described in Volumes II and III of these Annals.

The new method has several advantages: First, it may be employed on days when the sky is so variable or so cloudy in parts that the usual method could not be employed at all with satisfactory results. Second, the time consumed by the observation is only 15 minutes, and the time consumed by the reductions only about two hours, so that the solar constant may be obtained very much more quickly than before. Third, the new method may be employed many times in a single day, so as to yield a mean value supported by numerous independent observations.

In what follows we give the theory and construction of the pyranometer as taken from two papers entitled, respectively, "The Pyranometer—An Instrument for Measuring Sky Radiation,"[6] and "On the Use of the Pyranometer,"[7] both published by Messrs. Abbot and Aldrich. In addition to the data furnished by these papers, we give additional information which has resulted from the further use of the instrument. It was our purpose to devise a standard instrument for measuring the solar radiation scattered inward by the sky in daytime, and it was our hope that the instrument suitable for this purpose should also be applicable to the measurement of nocturnal radiation as well.

The name pyranometer,[8] selected for the instrument we have devised, is taken from Greek words (*πῦρ*, fire; *ἀνά*, up; *μέτρον*, a measure) signifying that which measures heat above. The name was chosen with reference to the fact that the instrument is designed to measure the energy of radiation to or from a complete hemisphere lying above the measuring surface.

PYRANOMETER A. P. O. 6.

Referring to the accompanying illustration (fig. 5)[9], figure 1 is a side view; figure 2, looking down from above; figure 3, an attachment not used in measuring

[6] Smithsonian Miscellaneous Collections, vol. 66, no. 7.
[7] Smithsonian Miscellaneous Collections, vol. 66, no. 11.
[8] We make our acknowledgments to Miss M. Moore and to Dr. Casanowicz for advice in selecting this name.
[9] The figure 5 is reprinted from a former publication in which the several parts of it were numbered 1, 2, 3, 4, 5. We leave these designations in order to facilitate explanation.

total sky radiation, but employed when it is desired to restrict the measurements to the sun alone; figure 4, a cross section taken at right angles to the view presented in figure 1 and omitting the wooden base and apparatus for shading the sun. In figure 5 are details showing the arrangement of the sensitive strips and thermocouples. The instrument shown is the sixth form we have devised. In the fifth form there is but one sensitive strip instead of two as shown here. The fifth form of instrument is more sensitive than the sixth form, but has a certain source of error which was to a considerable extent avoided in the sixth form, of which more will be said hereafter.

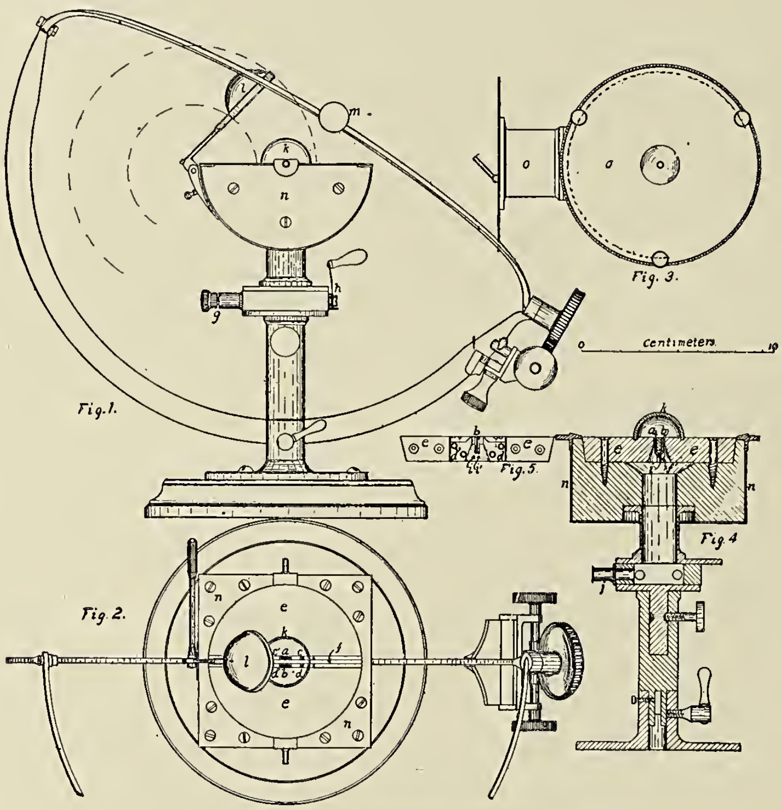


FIG. 5.—Views and details of pyranometer.

a and *b* are strips of manganin, each exposing surfaces 6 mm long and 2 mm wide. The strips are bent through 45° at the ends of the exposed portion and soldered with great care on to the lower parts of the split copper blocks c, c^1, d, d^1, in such manner that the solder goes exactly to the bend where the manganin strip becomes exposed. The strips *a*, *b*, are situated in the center of the polished nickel-plated copper block *e* and are separated the one from the other by the copper strip *f*. Electrical insulation between the strips *a*, *b* (with their attached copper blocks c, c^1, d, d^1), and the plate *e* and strip *f* are provided by means of thin vertical separating strips of mica, coming exactly to the common surface of the plate *e* and manganin strips *a*, *b*. Conductors (not shown) run from the blocks c, c^1, d, d^1, to the switch h,* and thence to the pair of binding posts g, of which only one of the two appears in figure 1. Between the switch h and the blocks c, c^1, d, d^1, the electrical current for heating the strips a, b, divides into two. Appropriate resistances are placed in the two circuits, so that although the strip b is ten times as thick as the strip a, and has a correspondingly smaller electrical resistance, compensation is provided by means of the said electrical resistances so that the current divides in the proper proportion to heat the strip a at exactly the same rate as strip b.

The two U-shaped thermo-elements, i, i^1, are arranged in series, with their warm and cold junctions respectively attached by thin waxed paper to the back of the strips a and b so that the difference of temperature (if any) between the strips a and b is indicated by means of a galvanometer connected into circuit with them by means of a flexible conductor (not shown in the figure) which enters the instrument by means of the tube j shown in figure 4. We employ tellurium-platinum for the thermo-elements on account of the great thermo-electric power of this combination, the noncorrosion of platinum by melting tellurium, and the small thermal conductivity of tellurium. The difficulty of forming tellurium into the U-shaped elements shown was at first considerable, but was overcome after some practice.

The principle of operation of the instrument may now be understood. Radiation falling simultaneously upon the strips a and b communicates to each the same quantity of heat; but the rise of temperature after a steady state is produced thereby is different in the two because the strip b is ten times as thick as the strip a, and so its thermal conductivity to the ends is greater. Hence a deflection of the galvanometer occurs. This deflection is balanced, after again shading the strips, by means of an electric current divided between the strips a and b so as to produce equal heating effects in each. By suitable adjustment the deflection of the galvanometer which was produced by the absorption of radiation is reproduced by the heating of the electric current. In these circumstances the energy of the electric current transformed into heat in either strip is equal to the energy of the radiation absorbed by either strip. The instrument is primarily designed to measure radiation on a horizontal surface, but it can be used in any position.

The remaining details of the instrument will be easily understood. k is an optically figured hollow hemispherical screen of ultra-violet crown glass 25 mm in diameter and 2 mm thick, whose purpose is to admit direct or scattered solar radiation, but to prevent the exchange of long wave-length radiation between the manganin strips and the sky. A nickel-plated shutter, l, is provided for shading the instrument from the sun or sky. A small metal screen, m, subtending 0.0011 hemisphere, is mounted on an equatorial axis operated by a worm-wheel arrange-

*In later instruments a separate switch has been provided to start the compensating current. The switch h has been employed to vary the resistance in the circuit of the thermal junctions and thus provide different degrees of sensitiveness.

ment. This screen is used to shade the sun from the strips, in case it is desired to measure the sky alone, and not the sun and sky in combination. A nickel-plated box, *n*, inclosing a wood block in which lies the plate *e*, is provided to keep the copper plate *e* from external disturbances of temperature by wind currents. Around this box, *n*, fits a nickel-plated cover, *o*, shown in figure 3, for use in observing the sun alone, in making comparisons with the pyrheliometer. When the cover shown in figure 3 is employed, the equatorial mounting of the sun screen *m* is removed, and the worm attachment is used for rotating the solar cover box *o*, just described.

The following data were used to determine the constant of pyranometer A. P. O. 6:

	Cm.
Length of strips between soldered portions	0. 623
Width of thin strip (mean of 5 places)	0. 198
Width of thick strip (mean of 5 places)	0. 201
	Ohms.
Electrical resistance of thin strip	0. 2740
Electrical resistance of thick strip	0. 0369
Electrical resistance in series with thin strip	0. 819
Electrical resistance in series with thick strip	0. 364
Assumed absorption of the lampblack	0. 98
Assumed transmission of the glass hemisphere (allowing for 2 reflections with index of refraction, 1.5)	0. 92

(Thickness of strips determined by weighing approximately 0.00034 and 0.0030 centimeter.)
(Resistance of the two thermo-couples in series 30 ohms.)

From these data the current in the thin strip is $\frac{.401}{1.494}$ times the current in the outside electrical heating circuit. Hence the current squares are as 0.0719 to unity. Hence the constant of the instrument (when glass covered) is

$$K=\frac{.0719\times.2740\times60}{4.185\times0.623\times0.198\times0.98\times0.92}=2.54,$$

so that the energy of radiation corresponding to a given heating current *c* measured in amperes is 2.54 c^2 calories (15° C) per cm^2 per minute. If used at night without glass for measurement of long-wave rays, the constant should probably be taken at[10]

$$2.54\times\frac{92}{100}\times\frac{98}{95}=2.41.$$

The reader will perceive that the instrument may be used for the sun alone, the sun and sky in combination, the sky alone by day, or by removing the glass screen *k* it may be used for nocturnal radiation. We have made numerous comparisons between the instrument as arranged for day observations and the pyrheliometer. A series of observations of this kind, interspersed by readings on the

[10] Recent experiments lead us to think the absorption factor for long-wave nocturnal radiation should be taken at 0.92 instead of 0.95. Further investigation is needed.

whole sky, is shown in Table 4. A close agreement with the results of pyrheliometer A. P. O. 9 is found for all altitudes of the sun when the pyranometer readings are reduced to vertical incidence. This confirms the accuracy of the instrument for observations of the entire sky.

TABLE 4.—*Summary of results of Mar. 31, 1916, North Tower, Smithsonian Institution.*

Secant Z.	Pyranometer A. P. O. No. 6.				Pyrheliometer A. P. O. No. 9. (calories).	Ratio: Pyrheliometer A. P. O. No. 9. / Pyranometer A. P. O. No. 6.
	Sky alone, glass on (calories).	Sun and sky, glass on (calories).	Sun alone, glass on (calories) (× Sec. Z).	Sun alone,[1] no glass on (calories) (× Sec. Z).		
1.340 (a. m.)				1.232	1.218	0.988
1.330 (a. m.)				[2] 1.084	1.193	[2] 1.10
1.235 (p. m.)	0.1783	1.150	[3] 1.200		[3] 1.190	[3] .991
1.383			1.013		.998	.984
1.400			.995		.990	.995
1.420			.949		.983	1.035
1.435			.975		.987	1.011
1.485				1.000	.993	.993
1.502				1.019	1.020	1.001
1.545				.947	.964	1.018
1.564				.956	.967	1.011
1.665	.1978					
1.689	.1703					
1.730	.1757					
1.768		.635	[3] .830			
1.802		.640	[3] .875			
1.874	.1463					
1.897	.1500					
2.050			.780		.775	.994
2.097			.798		.770	.966
2.280	.1359					
2.338	.1359					
2.415		.404	[3] .660			
2.480		.388	[3] .648			
2.567	.1220					
2.943			.668		.6825	1.021
3.055			.702		.680	.969
3.280			.608		.6325	1.040
3.420			.633		.6493	1.024
3.760	.0851					
3.90		.2471	[3] .613		.5706	[3] .930
4.05	.0945					
4.45				.504	.5220	1.034
General mean						1.006
Omitting observations Nos. 2 and 18						1.005

[1] Constant of instrument different from preceding column, allowance made for the removal of the glass being 8 per cent.
[2] Ammeter probably stuck.
[3] Result on sun obtained by subtracting sky from sun and sky combined.

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PYRANOMETER A. P. O. 5.

As stated above, we employed but one sensitive strip in pyranometer A. P. O. 5, embedding the cool junctions of the thermo-elements in the copper plate *e*. This form is several times as sensitive as pyranometer A. P. O. 6, so much so that we employed with it a potentiometer current to bring the very large galvanometer deflections to zero, and then balanced the potentiometer current by heating the strip. Unfortunately, a defect of this pyranometer is a secondary deflection, caused by the warming of the portion of the plate *e* under glass as soon as the shutter is opened. This secondary deflection was found very large, sometimes even as great as a quarter of the primary one. Its direction was sometimes in one sense, sometimes in the other, for reasons that we have not fully understood. There is, however, a method of reading whereby this source of error is very nearly eliminated.

As will be shown a little further on, it is not necessary to wait for the instrument to have produced a maximum deflection of the galvanometer. Excellent results can be obtained either with the two-strip or the one-strip pyranometer by using the first swing of the galvanometer. We are accustomed to adapt our galvanometers to the pyranometer so as to give a first swing in about five seconds, and during this interval of time the change of temperature of the surroundings which leads to the drift above mentioned is of little importance.

Under these conditions the error is practically negligible, and on account of its great sensitiveness pyranometer A. P. O. 5 is regarded as a valuable instrument.

Its constant is determined as follows: Length of strip, 0.628 cm; width, 0.294 cm; electrical resistance, 0.300 ohm.

$$\text{Radiation}=Kc^2 \text{ where } K=\frac{0.300\times 60}{4.185\times 0.628\times 0.294\times 0.98\times 0.92}=25.9.$$

We have employed this pyranometer A. P. O. 5 in numerous measurements of radiation from the sun, sun and sky, sky alone, and new-fallen snow. In comparisons with the pyrheliometer it gave very nearly equal results when corrected to vertical incidence. The reflecting power of snow for combined sun and sky rays was found to be 70 per cent.

The pyranometer is a very handsome instrument as constructed by Mr. Kramer. It may be used readily by anyone equipped with the auxiliary apparatus used with the Ångström pyrheliometer. Its readings on the sky and sun by day appear to be truly expressed in calories per square centimeter per minute, for in solar comparisons values found agree within experimental error for all zenith distances with those of our standardized pyrheliometers. While we have hitherto employed only ultra-violet crown-glass screens, it is obvious that such screens might be covered with stained gelatine, or other screens of special glass employed to restrict the measurements to special regions of spectrum, as might be desirable in botanical investigations. While the two-strip form is preferable from its greater freedom from temperature disturbances, the single-strip form is so much more sensitive that for observations in deep shade, as in a forest, it would be more suitable.

METHOD OF USE.

As we have said, in our first observations we allowed the galvanometer to reach a maximum deflection and we found that nearly 30 seconds must elapse after throwing on a heating current before a new state of temperature equilibrium becomes completely established, as shown by a steady state of the galvanometer. Accordingly we adopted the custom of waiting 30 seconds after each exposure to radiation, in order that the steady state might be reached, before recording the galvanometer deflection. At Mount Wilson our attention was drawn to a phenomenon unnoticed at Washington. When exposing the instrument to sunlit sky, through the glass hemisphere used to cut off long-wave rays, the deflection of the galvanometer came to a maximum within 5 seconds, and then continually decreased for as much as a minute thereafter. The decrease in 30 seconds was a very considerable part of the whole sky deflection. Our original method of reading thus proved quite arbitrary, for there was no reason to suppose the reading at 30 seconds after exposure was better than at 20 or 40 seconds. A similar drift of the galvanometer, but very small relatively to the whole deflection, was observed after the lapse of about 20 seconds after exposure to the sun through the glass hemisphere. Whenever the glass hemisphere was removed, whether observing the sky by day or by night, or the sun, the deflection increased gradually for about 20 or 30 seconds, as with the heating current.

A clue was soon found. Generally if the sky is observed by day in Washington, with glass removed, almost no deflection occurs. The gain of heat to the blackened strips from scattered sun rays at Washington is almost equal to the loss of heat by emission of long-wave rays toward the sky. But if the observation is made on Mount Wilson a large negative deflection occurs. At summer temperatures of observation the scattered sun rays at Mount Wilson are by no means equal in energy to the long-wave rays emitted toward the sky. Now it is well known that glass is a nearly perfect absorber of these long-wave rays, and hence is a nearly perfect radiator of them as well. But, on the other hand, the brightly polished metal cover, used as a shutter to the pyranometer, radiates almost nothing, being a nearly perfect reflector for long-wave rays. But the nickel-plated cover absorbs about 30 per cent of the shorter-wave solar rays which meet it, and thereby is warmed, and warms the glass close below it by air convection. Now when the cover is removed the glass can cool rapidly by radiation, and as it is almost completely transparent to solar rays, it is hardly warmed at all by them. Hence the glass after exposure grows cooler than before, and as it subtends a full hemisphere, it tends strongly to reduce the temperature of the blackened strips below, thus causing the gradual decrease of the galvanometer deflection.

Having discovered the cause of error, the remedy was seen to lie in shortening the period of exposure so much that there would not be time for the glass to become appreciably cooled on the inside. We therefore began to investigate the behavior of the galvanometer with a view to observing the first swing instead of the permanent deflection.

As is well known to many readers, the time of swing of a moving coil galvanometer is shortest on open circuit, and increases as the external resistance in closed circuit diminishes, until at length no second swing occurs. Of two galvanometers tried by us both gave about 2 seconds' time of single swing on open circuit, but when closed on the pyranometer alone, one gave no second swing at all, the other a second swing of about $\frac{1}{20}$ the magnitude of the first. By inserting 75 ohms or more resistance in series with the first galvanometer, it also gave a second swing, and the time of single swing of each galvanometer, when just giving a second swing, was about 4 seconds.[11]

We next made tests with the heating current and with radiation at night to see if the first swing is proportional to the final deflection. We found this to be the case. We also found that both with the heating current and with nocturnal radiation, not only the first swing but the deflection, attained after 10, 15, 20, 25, and 30 seconds, maintained certain definite proportions to the final deflection, no matter what the strength of the current, or the intensity of the observed radiation. We also found that when proper allowance was made for the nonuniformity of sensitiveness of the galvanometer for large and small deflections, the deflections observed due to heating currents were exactly proportional to the square of the heating current employed.

These facts ascertained, the way seemed clear to avoid the source of error mentioned above, and at the same time to increase greatly the rapidity of reading the instrument, and also to avoid drifting of zero, so apt to occur in long exposures. In short for all daylight observations we adopted the plan of reading first swings, and of omitting exact adjustments of the energy of the heating currents to equal that of the observed radiation. Our present procedure in day work is as follows:

(1) On exposure to radiation, read the first swing of the galvanometer, and immediately close the shutter.

(2) After 30 seconds or more throw on a heating current sufficient to cause a deflection approximately equal to that from the radiation, and again note the first swing, and the exact strength of the heating current.

(3) Let D_R be the deflection due to radiation, D_C the deflection due to heating current, C the strength of current, and K the constant of the pyranometer. (For

[11] Moving coil galvanometers may often be arranged to give a second swing by removing the iron which lies within the coil, and which tends strongly to damp the vibrations.

our pyranometer, A. P. O. No. 6, $K=2.54$.) Then the intensity of radiation $R=K\frac{D_R}{D_C}C^2$.

When in the use of the pyranometer deflections are observed too large for convenient reading, a suitable resistance is used in series with the galvanometer. In our new instruments a little switch is provided for this purpose and marked "G." It provides three degrees of sensitiveness according as open or closed on one side or the other.

From our experiments it appears that when proper allowance is made for non-uniformity of the sensitiveness of the galvanometer scale, the deflection observed is exactly proportional to the square of the strength of the heating current applied to the pyranometer. Hence it follows that if a certain current C_1 produces a deflection D_1, and a certain radiation R produces a slightly different deflection D_2, the radiation R would be exactly compensated by a current C_2 such that $\frac{C_1^2}{C_2^2}=\frac{D_1}{D_2}$. This valuable result enables us to dispense with the tedious process of producing exact compensations.

TABLE 5.—*Sample daytime pyranometer observations on Mount Wilson.*

AUG. 7, 1916.

Time.	Zero.	First swing.	Deflection D.	Object.	Current (C) (amperes).	C^2.	$\frac{C^2}{D_C}$.	Calories.
h m s								
2 28 0	11.00	14.26	3.26	Sky...	....	....	....	0.137
	10.88	13.78	2.90	Current	.223	0.0497	.0171	....
30 30	11.15	14.47	3.32	Sky	....	....	....	0.140
	11.28	14.48	3.20	Current	.231	.0534	.0167	....
33 30	14.98	21.96	6.98	Sun and sky	....	....	....	1.240
	14.99	20.18	5.19	Current	.607	.368	.0709	....
35 30	14.99	21.86	6.87	Sun and sky	....	....	....	1.220
	14.92	20.30	5.38	Current	.610	372	.0691	....

TABLE 6.—*Comparison of pyranometer and pyrheliometer.*

[Observations made with pyranometer A. P. O. No. 6 and secondary pyrheliometer A. P. O. No. IV. Results in calories per cm² per minute.]

AUG. 6, 1916; HOUR ANGLES 1h. 52m. TO 1h. 37m.

Secant Z	1.160	1.148	1.137	1.132
Pyranometer × secant Z	1.462	1.464	1.471	1.451
Pyrheliometer	1.477	1.469	1.467	1.460
Difference	+ .017	+ .005	− .004	+ .009
AUG. 7, 1916; HOUR ANGLES 5h. 35m. TO 5h. 23m.				
Secant Z	4.017	3.808	3.620	3.448
Pyranometer × secant Z	1.064	1.079	1.104	1.109
Pyrheliometer	1.067	1.077	1.087	1.118
Difference	+ .003	− .002	− .017	+ .009

From these experiments it appears that the pyranometer gives values of solar radiation comparable in accuracy with those observed with the pyrheliometer. As the results are of satisfactory accuracy at both great and small zenith distances, the pyranometer may be supposed to give accurate results on the sky, which involves all zenith distances.

DIRECTIONS FOR OBSERVING AND REDUCING OBSERVATIONS.

Employ a galvanometer of not more than 60 ohms resistance giving a first swing within 5 seconds. If too sensitive diminish its deflection by a suitable resistance in series. Employ a heating current adjustable from zero to 0.8 ampere. If a storage battery is available it will be found the most satisfactory source to furnish the current, but dry cells may be used. A simple slide wire rheostat is required for nocturnal work. Employ an accurate ammeter for reading the current strength.

Daylight work.—Place the pyranometer on a level surface in the place where the intensity of radiation is to be measured. If the sun is sometimes to be shaded off adjust the flat arc (which is the sun-shade support) to lie north and south, set the arc to the latitude of the place, and set the shade to cast its shadow centrally on the pyranometer. The shade is to be turned forward as the sun goes westward. Employ the glass hemisphere in measurements of direct or scattered sunlight. Remove it for nocturnal measurements. Be sure the glass screen has no dirt or finger marks upon it. (The glass may be cleaned by breathing upon it and while damp wiping with clean cloth or cotton.) When ready to observe, read the position of the galvanometer scale, open the shutter, read the first swing, close the shutter, wait a half minute, read the galvanometer, throw on a current suitable to give about the same swing, read the first swing, and read the current strength.

Let the deflection due to radiation be D_R, that due to current be D_C, the constant of the instrument be K (=2.54 for pyranometer A. P. O. No. 6 with glass on). Then the result in calories per centimeter^2 per minute is $K\frac{D_R}{D_C}C^2$. Where there is non-uniformity of the galvanometer scale, as here, it is of course necessary that D_C shall not differ greatly from D_R. We generally form the quotient $\frac{C^2}{D_C}$ and take the mean of several values of it to use for neighboring values of radiation.

SOURCES OF ERROR FROM A GLASS COVER OVER THE PYRANOMETER.

Dr. Ångström [12] and Dr. Dorno [13] have questioned whether the glass cover does not introduce considerable errors in the pyranometer.

We have employed optical glass, optically figured to concentric spheres within and without. Upon reading a page of print through the glass it is clear that

[12] Monthly Weather Review, November, 1919.

[13] In a personal letter.

very little distortion of the field occurs within an area considerably bigger than the sensitive strips. Thus we feel safe as regards distortion, even of the solar image, much more of so approximately uniform a source of emission as the sky.

In early pyranometers we employed Jena ultra-violet crown glass. During the war this was not available, but the J. A. Brashear Co., of Pittsburgh, furnished us three small sample 60° prisms described, respectively, as No. 3637 boro-silicate crown, No. 6153 and No. 5270 light crown.

With these prisms we made spectrum energy curves, and thus determined their dispersions. From the point of view of uniformity of dispersion they ranked in the order No. 3637, No. 5270, and No. 6153, but none were quite as favorable as ultra-violet crown because they all give less dispersion in the infra-red and more in the ultra-violet than it does.

Nos. 3637 and 5270 were cemented together with glycerine to form a plane parallel plate 2.3 cm thick. This was interposed in the beam and spectrum energy curves taken alternately with and without it. Absorption first became noticeable at 0.36μ in the ultra-violet and at 1.9μ in the infra-red. At 0.34μ the absorption of the plate reached 45 per cent, and at 2.35μ, 40 per cent. As the thickness of the hemispherical glass shells is but 3 mm, clearly no absorption of consequence can occur between 0.34μ and 2.35μ. Beyond these limits the absorption would quickly be practically total.

In view of this we are to suppose that for sunlight the hemispheres will transmit 92 per cent, since 8 per cent is the combined reflection of the two surfaces of 1.5 index of refraction. Confirming this estimate, we refer to columns 4, 5, and 7 of Table 1 of our paper "The Pyranometer," quoted also above as Table 4, which give results computed by making the assumption just stated. These show no difference between comparisons of the pyrheliometer and the pyranometer with and without glass when this correction of 8 per cent is applied.

In our paper "On the Use of the Pyranometer," from which we have quoted, we drew attention to a source of error which depends on the warming of the nickel-plated shutter by absorption of sky radiation before the instrument is exposed. From the shutter the heat convected by the air is communicated and warms the glass, which being almost completely absorbing is therefore almost completely radiating for long-wave rays. Hence when the shutter is opened the glass rapidly cools by radiation to the cold heights of the atmosphere. Subtending a hemisphere, the cooled glass tends strongly to cool the sensitive strips by exchange of radiation. We sought to diminish this error by shortening the period necessary for reading to a single swing of the galvanometer, usually about 4 seconds.

We have lately investigated the magnitude of the error yet remaining. A "daylight" incandescent lamp attached beneath a horizontal asbestos screen was placed above the pyranometer so that it could be instantly swung aside and extinguished as the screen was removed. Just above the screen was a large flat-bottomed vessel of ice water intended to simulate the sky in out-of-door work.

Exposed to the lamp, the pyranometer with the glass *on* indicated +0.204 calorie per centimeter ^{2} per minute. Exposed to the ice-water tank with glass *off* the pyranometer indicated −0.097 calorie per centimeter ^{2} per minute. After remaining under the lamp with shutter on and glass cover in place till the galvanometer became steady, the lamp with the screen was suddenly drawn aside and extinguished leaving the room in darkness, and (the glass still being on) the shutter was opened. The mean result of several experiments gave the following galvanometer deflections after elapsed times stated. The sensitiveness was such that 1 mm deflection corresponds to 0.0015 calorie per centimeter ^{2} per minute.

Elapsed time, seconds	7	17	27	37	47	57
Deflection, millimeters	1.25	3.5	5.8	7.8	9.6	11 0

By a slight extrapolation from these results it appears that 1.5 seconds elapse before the deflection of the galvanometer begins, and that the deflection runs as follows:

Elapsed time, seconds	1.5	3	4	5	7	10
Deflection, millimeters	0	0.35	0.6	0.8	1.25	2.0
Calories per centimeter ^{2} per minute	0	0.0005	0.0009	0 0012	0 0019	0.0020

The magnitudes of the radiation quantities involved correspond fairly closely with those of ordinary observations of sky radiation. We conclude therefore that the after effect of warming of the nickel-plated shutter may cause the pyranometer to read $\frac{0.0009}{0.15}=0.6$ per cent too low when readings like those of August 7, 1916, on Mount Wilson [14] are made with a galvanometer of 4 seconds' single swing. For other conditions see the table above.

USE OF THE PYRANOMETER FOR NOCTURNAL RADIATION MEASUREMENTS.

As stated above, we hoped to use the pyranometer for measurements of the long-wave radiation such as the earth sends out to space. For this purpose the glass screen would be removed so as to permit the exchange of the long wave-length rays which are not transmissible by glass. It is not to be supposed that the loss of radiation which a body at the earth's surface suffers toward space really is a measure of the intensity of the long-wave rays which are transmitted to outer space by the atmosphere. We have, in fact, an exchange of radiation. The rays of the measuring instrument emitted at a certain temperature going upward are partially balanced by the rays from the sky emitted at a lower temperature coming

[14] See "On the use of the Pyranometer," Smithsonian Miscellaneous Collections, vol. 66, no. 11, p. 7.

downward. Theoretically it would be possible that the transmission for the rays in question entirely through the atmosphere should be zero. If that were the case, the apparent outgoing radiation from the instrument at the surface of the earth would really be merely the difference of intensity between radiation emitted at the surface temperature of the earth and the radiation of the materials of the atmosphere emitted at the lower temperature which prevails high above the earth's surface.

Although this consideration is always to be borne in mind in considering measurements of nocturnal radiation, yet measurements of the outgoing radiations from a surface at sea level are of importance to meteorology. The earth, to be sure, varies from place to place in its radiating capacity, being composed of water, snow, ice, rock, sand, vegetation, the emissive powers of which differ greatly. Still it is to be remembered that over 70 per cent of the surface of the earth is composed of the oceans, and that on the land the vegetable material also contains much moisture, so that the radiating power of the earth as a whole is nearly the same as the radiating power of water. It is well known that water is almost completely absorbing for rays of great wave length, and so it must be, according to Kirchoff's law, almost a perfect radiator as well. Thus very approximate information as to the radiating power of the earth as a whole would be furnished by using for the measuring apparatus a surface which meets the requirements of the so-called "black body" or perfectly radiating substance.

It is at this point that the pyranometer, as an instrument for measuring nocturnal radiation fails, for although lampblack, with which its sensitive surface is covered, is an excellent absorber for short wave-length rays such as those most plentifully received from the sun, yet for the very long wave rays, such as are here in question, mainly between wave lengths of 10 and 50 microns, the absorbing and emitting powers of lampblack are very imperfect. Moreover, the absorption coefficient for lampblack is not well known for very long wave rays and, indeed, probably varies from surface to surface. Beyond the wave length of 15 microns very little is certainly known about it. In our earlier work we made the assumption that the lampblack, which for the visible and upper infra-red spectrum absorbs nearly 98 per cent, is only 95 per cent absorbing on the average for the rays in question. We find, however, that the instrument of Dr. Ångström, called the pyrgeometer, which is primarily designed for the measurement of nocturnal radiation, gives values from 20 to 30 per cent higher than the pyranometer under this assumption.

Recently there has been constructed at the Astrophysical Observatory a new radiation instrument in which the hollow-chamber principle of the absolutely "black body" has been employed. Mr. Aldrich has found in preliminary comparisons with it that probably the pyranometer is somewhat farther from being a perfect radiator than we had supposed, so that, as stated in a footnote above, it may be better to adopt a lower value than 0.95, perhaps 0.92, as the average absorbing and emitting power for its sensitive strip. If so, measurements made by Smithsonian observers at the eclipses of 1918 and 1919, and such other measurements of nocturnal radiation as have been made with our pyranometers hitherto, should be increased 3 per cent. The actual value of the correction is as yet not satisfactorily determined.

In employing the pyranometer for nocturnal radiation work, it is immaterial whether it is used by the method of the first swing of the galvanometer or by the method of compensation, such as is employed in the instruments of Ångström. Of course, if observing by the method of first swing, the effect of introducing the electric current will be to produce a deflection in the opposite sense from that produced by exposing the instrument to give nocturnal radiation. This, however, is not material if the scale of the galvanometer has been investigated and proper corrections are employed for the variation of sensitiveness of the galvanometer at different parts of its scale.

If the pyranometer were to be used a great deal for nocturnal radiation work, it would be very desirable to insert in the copper block a small thermometer so as to indicate the temperature of the instrument. However, almost the same result is obtained by taking the temperature of the surrounding air, providing that the air temperature is not varying rapidly and that the instrument has been freely exposed to the cooling influence of the air for a half or three-quarters of an hour before the readings are commenced. This dependence of the reading on the temperature of the instrument, which often differs by appreciable amounts from the temperature of the surrounding air, is a drawback to the use of the pyranometer as a nocturnal instrument, for it requires the observations to be delayed for a considerable time until the temperature of the surrounding air is acquired, and prevents the measurements from being of much value at times when the air temperature is rapidly changing. It would be very desirable if an instrument for such purposes could be designed with a constant temperature appliance so that the radiating strip would always be of a fixed selected temperature, as for example, 0° C or 20° C. This, however, involves sources of error which are hard to overcome, and so hitherto we have contented ourselves with the pyranometer as it is.

The measurement of nocturnal radiation is one of great interest and deserves very serious attention. We ourselves are endeavoring to perfect an instrument of the "black body" or perfect radiator type which will meet the various requirements of the problem, but several such instruments of different types ought to be prepared in order to make sure that the readings obtained are actually what we suppose them to be.

USE OF THE PYRANOMETER IN THE MEASUREMENT OF THE SOLAR CONSTANT.

We have realized for many years a weakness of our measurements of the solar constant of radiation. They depended on the uniformity of the transparency of the sky during several hours. If the sky is becoming clearer during this interval, our result is too high. If the sky is becoming less clear, our result is too low. What we earnestly desired to find was a method by means of which the transparency of the sky could be determined from observations at a single point of time. One method of attack on this problem has occurred to us, based upon the common dependence of the brightness and the transparency of the atmosphere on the quantity of haze with which it is loaded. As is well known, if the sky becomes more hazy, its brightness is increased and its transparency is diminished, and vice versa if it becomes less hazy.

Haziness depends partly upon the humidity and partly upon the presence of dust such as is blown up by the wind or floats about after volcanic eruptions. We desired to take account of both these causes of haziness. The humidity, as was shown by Mr. Fowle,[15] may be determined by a consideration of the depth of the infra-red absorption bands ρ or ϕ. We are accustomed to use the value at ρ in our new method of solar-constant observing. As Mr. Fowle says, "Across a band produced in a bolographic energy spectrum of the sun by the atmospheric water vapor a line is drawn and the transmissibility is measured by the ratio of the ordinate at the bottom of the band to the corresponding ordinate of the line drawn across the top." Calling the ordinate at the bottom of the band ρ and the ordinate at the corresponding point on the smooth line over the top ρ_{sc}, then the ratio ρ/ρ_{sc} is an index to the quantity of water vapor existing between the observer and the limit of the atmosphere. As shown by Mr. Fowle, a certain part of the coefficient of atmospheric transmission depends upon the value of ρ/ρ_{sc}, so that we are justified in using this function ρ/ρ_{sc} as at least a partially *defining* factor for the haziness and transparency of the atmosphere at the time in question. But as stated above the haziness is not solely dependent upon the quantity of water vapor, for there may exist more or less heavy loads of dust in the atmosphere according to the direction and intensity of the wind, and according to variations in the haziness produced by the volcanic eruptions which take place from time to time, and which leave fine dry dust at high altitudes often for many months or even for years.

In order to take account of this latter condition of dry dustiness we have employed the pyranometer, stopped down to an angular aperture of 30°, and mounted upon an equatorial stand so as to present its sensitive surface at right angles to the solar beam. The direct beam of the sun, however, is cut off during such observations by means of the little circular screen provided for this purpose.

[15] See Annals, Vol. III, p. 182.

Thus the observation is limited to a zone of sky, not including the sun, but immediately surrounding it for 15° in all directions.

Let us call the reading of the pyranometer under these conditions and at the fixed zenith distance of the sun which we may take, for example, at two air masses, as P_2. Divide this quantity by the ratio $\frac{\rho}{\rho_{sc}}$. We then obtain a function $\frac{P_2}{\rho/\rho_{sc}}$, which we may call F_2. We have found that when values of the function F on many days are plotted as abscissae against values of the atmospheric transmission coefficients at a definite wave length on corresponding days as ordinates, the curve for each wave length assumes the form of a straight line approximately though it deviates from the straight line for the shorter wave lengths in the sense of becoming a little convex toward the axes of coordinates. The transmission coefficients for such a station as Calama, at the altitude of 2,500 meters, are nearly all between the values 0.8 and unity, and the majority of them exceed 0.9. The fluctuations of the values of the transmission coefficients are small, seldom exceeding 5 per cent, and for the great proportion of the spectrum seldom exceeding 2 per cent. The fluctuations of the function F, however, are relatively very large. Values of F range from 100 to 1,500 on a certain scale, so that associated with these small changes in "a" there are changes of F amounting to many fold.

We collected the results of 60 days of observing at Calama, in Chile, as a basis for building up the new method. There were given for each of these days the value of the solar constant as determined by our older and usual process, the values of the brightness of the sky for 15° round the sun measured by the pyranometer at air mass 2 and air mass 3, the values of $\frac{\rho}{\rho_{sc}}$ of the corresponding air masses, and the values of the direct sun rays observed by the pyrheliometer at the corresponding times. We plotted the transmission coefficient obtained by the usual process against values of the function F, and found at all wave lengths that the plots lay well distributed and near the best representative line. The accompanying illustrations, Figs. 6 and 7, show the results obtained at air mass 2 and air mass 3. From them one gains the impression that the value "a" chosen to represent the observed value of the function F would seldom differ by more than half of 1 per cent from the value of "a" which would be found by the complete spectrobolometric process as we formerly used it.

Our detailed application of the new method is as follows:

We determine by means of the pyranometer and the spectrobolometer observations at air mass 2 and at air mass 3 the value of the function which we call "F." We enter each of the plots correlating "F" and "a" with the value so obtained. Thus we derive the values at "a" for all wave lengths corresponding to the value of "F" which, as we have said, may have been obtained at air mass 2 or at air mass 3. Ordinarily we employ observations at both these air masses and even observations at air masses less than 2 in order to obtain several checks on the accuracy of the solar-constant value of the day. Having in this way obtained the atmospheric transmission coefficients we extrapolate from the given air mass by means of logarithmic calculations to determine the intensity of the spectrum energy curve as it would be at zero air mass, as based upon the measured intensities at all wave lengths of the bolometric energy curve at the air mass in question. The reduction of the extrapolated energy curve thus obtained to give the solar constant in terms of calories per square centimeter per minute is almost identical with the corresponding reduction made in the application of the old method, examples of which have been given hitherto. The only difference lies in the new brief method of fixing the values of the atmospheric transmission coefficients for all wave-lengths. This by the older fundamental process required bolographs at different air masses, and involved several hours of observing and many hours of computing, as well as a sky of unchanged transparency during the observing. The new method requires only about 10 minutes for completing the observations, and between one and two hours for their reduction.

I now give the results of the comparison which was made at Calama between the old and the new methods for 53 days extending from December, 1918, to June, 1919:[16]

TABLE 7.—*"Short-method" work. Numbers of days yielding deviations of given magnitudes.*

Calories.	0–.005	.005–.010	.010–.020	.020–.030	.030–.040	.040–∞
No. +	7	4	8	4	5	4
No. −	5	2	6	4	2	3

The observers at Calama, in studying the causes of the larger discrepancies between the old and the new method which were revealed by this comparison, are of the opinion that in many instances the discrepancy is due to changes in the transparency of the sky which affected the old method but not the new, so that on days when the sky was decidedly clearing, as indicated by various observations which were made, visual and otherwise, the new method has given lower results than the old, while on days when the sky was becoming more hazy the new method gave higher results than the old.

A similar basis for the application of the new method is being made in Arizona observations, and it is expected in future to employ it on a great proportion of observing days at all spectrobolometric stations, though not exclusively, lest errors should creep into the work.

[16] At a later page it is shown that certain corrections should be applied to the short method values, which would materially improve these preliminary results.

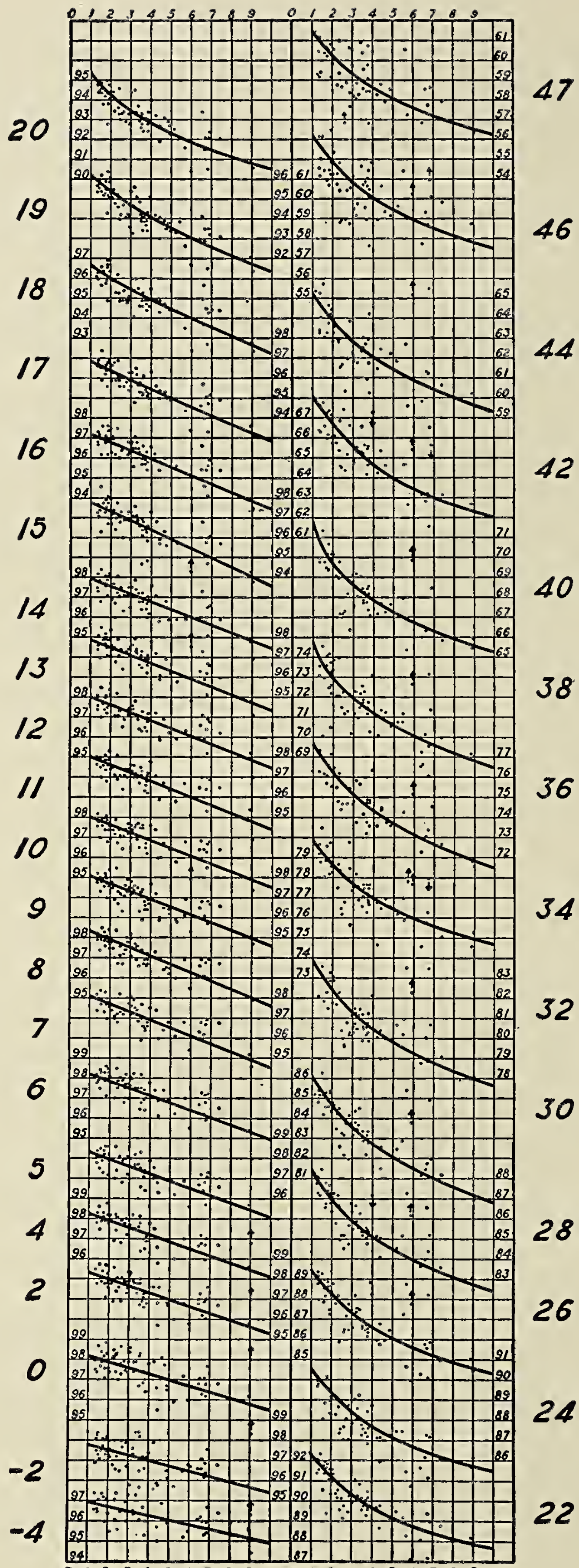

FIG. 6.—Calama short-method plots. Air mass 2.

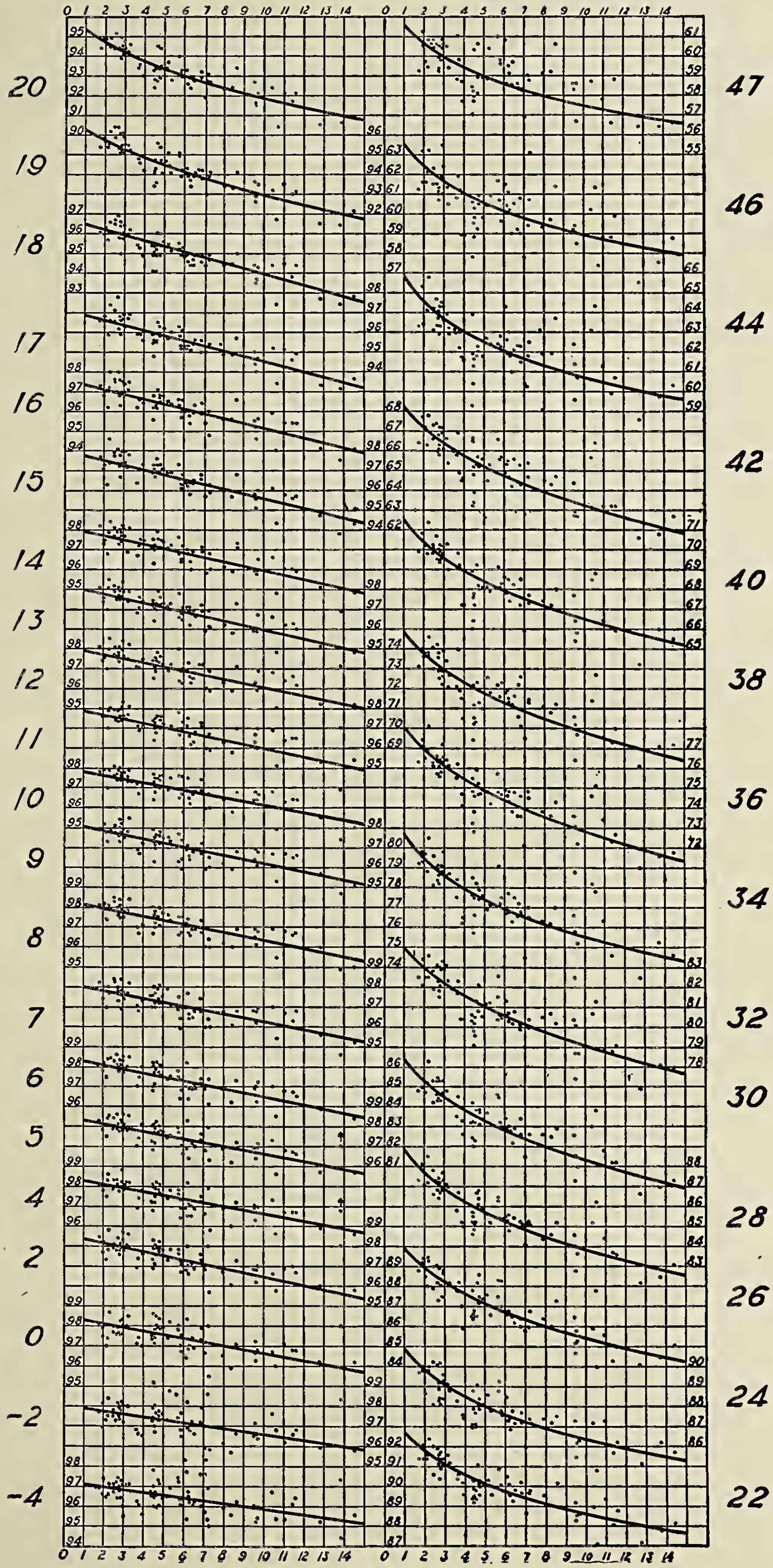

FIG. 7.—Calama short-method plots. Air mass 3.

The new process requires but two or three hours of work where the old required about 15, so that if it continues to appear as satisfactory as now a very great gain in labor will result from it. Not only is this so, but a still greater gain we think will come in accuracy, for we have now eliminated the fruitful source of error depending on the variability of the atmospheric transparency during the observations.

Another advantage of the new method is that on days when the early morning is unsuitable for observation, but later it clears away so as to be satisfactory for 15° around the sun, a good solar-constant value can be obtained by the new method where nothing at all of value could be obtained by the old. It was found that at Calama the increase in the number of days fit for observation, owing to this improvement, averaged four a month. Also some of the days when we would have had great distrust of the results, owing to probable changes of transparency, will now be made of almost or quite equal excellence to the others.

3. THE SLIDE-RULE EXTRAPOLATOR.

In all the earlier work of the observatory on the solar constant of radiation we were accustomed to take logarithms of the intensities of the radiation at the different wave lengths as measured upon the bolographic curves. After having corrected these logarithms for small changes in the sensitiveness of the spectrobolometric apparatus, as determined by comparisons with pyrheliometer results, we plotted the said logarithms as ordinates against air masses as abscissæ upon large sheets of cross-section paper. The observer then, with a thread looped about a pin beyond the edge of the paper as a center, adjusted the thread when held taut by one hand so as to represent as best he could the positions of the several plotted points so as to furnish the best representative straight line. He then read off the intersection upon the scale of ordinates corresponding to zero air mass the logarithmic value of the intensity outside the atmosphere, and by the aid of a logarithm table determined the numerical value corresponding. All of this work was tedious and time consuming.

When the Institution decided to send the expedition to South America to observe there daily, as far as could be, the solar constant of radiation, it was felt very desirable to shorten if possible this laborious process. It occurred to us that if the slide rule, so much used by engineers and physicists, could be brought into the process, much of the calculation could be avoided. Accordingly we devised a special machine comprising eight 16-inch slide rules and appropriate accessories, adapted for making the graphical extrapolations. This machine is shown in the accompanying illustration, figure 8, and has the following characteristics:

Upon a wooden support is fastened by hinges a rectangular steel frame capable of being tilted to any desired angle with the horizontal most comfortable for the observer. On the lower horizontal rail of this frame is fixed a scale of equal parts, and there slides along this scale, supported by the lower and upper horizontal bars

FIG. 8.—THE SLIDE-RULE EXTRAPOLATOR.

of the upper steel frame, six slide rules, s^1, s^2, s^3, s^4, s^5, $s.^6$ These rules may obviously be set to any desired positions along the horizontal scale, and when properly set are clamped by means of small vise clamps to the steel frame. At the left of the frame corresponding to zero of the horizontal scale are fixed two slide rules, SO, SO′, one in continuation vertically of the other, parallel to the rules s^1, s^2, etc., and all at right angles to the horizontal scale.

On the double length slide rule is a common slider, *f*, which at its upper extremity carries a side arm which reaches to the left. At a distance equal to ten divisions of the horizontal scale there is attached to this side arm a pivot which carries one end of the fine wire whose other end is attached to a sliding box at the right of the steel frame containing a spool having a winding spring adapted to keep the wire always taut.

It will be clear to the reader that when the hair-line sliders on the slide rules, s^1, s^2, s^3, etc., are adjusted to give the readings upon the scales corresponding to the observed measurements of intensity on the six bolographic energy curves, and the sliders themselves have been adjusted in longitudinal position to correspond with the air masses at which these energy measurements were made, then since the scales of the slide rules are logarithmic, the points determined by the hair-line sliders where they intersect the scales of the slide rules will correspond to the points formerly so laboriously plotted on the large sheets of cross-section paper. Thus when the wire is laid to correspond with the points so determined and the intersection of it with slide rules SO, SO′ is read it will give the numerical value corresponding to the intensity at the observed wave length as it would be outside of the atmosphere. By the device of continuing the wire until it reaches a point in abscissae equal to one air mass in negative value, the difference between the position where the wire cuts the slider, *f*, and the top of the slider, *f*, where the side arm intersects it, will correspond to the logarithmic value of the transmission coefficient of the atmosphere. Thus the observer has only to read the value off upon the slider, *f*, to obtain in numerical terms the atmospheric transmission coefficient which formerly had to be derived by taking a value from a logarithm table.

A further advantage of the apparatus is this: Correcting factors determined by aid of the pyrheliometer to allow for changes of sensitiveness of the spectrobolometer must be applied in common to all the ordinates of each of the several bolographic curves. These values usually lie between 0.98 and 1.02. They may be set up once, for all bolographs of the day, on the sliding scales of the individual slide rules s^1, s^2, etc., and the intensity values are to be laid off on these scales rather than on fixed scales of these slide rules. Thus even these corrections are made graphically rather than by computation.

The instrument is a very great assistance in the work. It saves nearly half of the computing time formerly necessary in the determination of a value of the solar

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constant of radiation and has proved so successful that a similar slide-rule extrapolator has been made and is now in use in Arizona. It is not required for reducing observations in the new method.

4. STELLITE MIRRORS.

In our earlier investigations with the spectrobolometer we have always regretted the fact that the transmission of the optical apparatus varied from time to time on account of the tarnishing of the silvered glass mirrors which we employed in the optical train. As mentioned in Volume III of these Annals, we attempted to avoid this difficulty at the time of the Mount Whitney and Algerian expeditions by the use of mirrors of other substances. In the Mount Whitney expedition we employed magnalium and in the Algerian expedition speculum metal. We found, however, that the magnalium tarnishes rapidly in the presence of moisture, and even the speculum metal, although more stable than silver, tarnishes too rapidly. In the year 1915 we made experiments with small sample mirrors of stellite, an alloy said to be composed of chromium, cobalt, and tungsten. The samples of this alloy were furnished us by the Haynes Stellite Co., of Kokomo, Indiana, through the kindness of Mr. Haynes who took a very great interest in the matter. The four sample mirrors were of two grades of stellite, two of each grade. We used them in pairs and were able to determine the reflecting power of the material for different wave lengths with the result which follows, which indicates the percentage reflected with one reflection for different wave lengths in the spectrum.

TABLE 8.—*Reflecting power, two samples of stellite.*

Wave length (Ångströms)........	3,350	3,400	3,510	3,670	4,180	4,730	5,310	6,530	7,690	9,800	12,200	21,000
Per cent reflected:												
Sample A....................	46.5	47.0	49.0	50.5	55.5	59.0	61.5	64.5	67.0	69.5	71.0	77.5
Sample B....................	45.0	46.0	48.0	50.0	53.5	56.5	58.0	62.0	64.0	66.5	68.0	74.5

From these results it appears that stellite differs little from speculum metal, nickel, steel, and platinum in reflecting power, though inferior to magnalium and still more to silver for most wave lengths. In one respect, however, it has an advantage over silver, that it has no transparent band near 3,100 Ångström units, as occurs in silver. The permanency of these mirrors leaves nothing to wish for.

We left these sample mirrors out of doors during a large part of one winter, subject to the fall of snow and the accumulations of dust and the attack of vapors of all kinds which occur in the air of Washington, but when the mirrors were rubbed off with cotton at the end of this exposure, they were found to be as perfect as when put out, although silver mirrors subjected to the same treatment would have been absolutely ruined. We were informed also that the mirrors could be subjected to the attack of acids, even in hot condition, without depreciation. We have not tried this test.

In view of all this, it was decided to obtain larger mirrors for use with the spectrobolometer on Mount Wilson. Castings were at length produced by the Haynes Co. which were sufficiently large for the purpose, but several attempts were necessary owing to the porosity which frequently spoiled the surface, but which was not observable on the outside and only appeared after grinding. At length, however, suitable surfaces were obtained for the rectangular flat mirror and the circular concave mirror of the spectrobolometer, and this pair of mirrors, constructed by Mr. M. E. Kahler, of Georgetown, D. C., was installed on Mount Wilson in July, 1916. The use of them proved so satisfactory that we obtained from the Haynes Co. two 10-inch disks, from which Mr. Kahler prepared flat mirrors to use on the coelostat at Mount Wilson, and these were installed in the autumn of 1917. Thus the whole train of mirrors employed for the spectrobolometric work on the solar constant of radiation at Mount Wilson, California, was composed of the metal stellite, and no appreciable tarnishing took place. From time to time a slight milky bloom forms, but this may be easily rubbed off with cotton, leaving the mirrors equally as good as they were at first.

With this favorable experience, the South American station was also equipped with stellite mirrors, two for the spectroscope having been installed there in July, 1919. The two others for the coelostat were installed in April, 1920. Experiments have been made repeatedly on Mount Wilson to determine the reflecting power of the stellite mirrors for the coelostat. The following results were obtained as the mean of closely agreeing determinations of July 25, July 4, August 21, and October 9, 1918. In the following table, line 1 gives the prismatic deviation in minutes of arc from ω_1. The second line gives the corresponding wave lengths in microns. The third line, the mean value of the reflecting power of the coelostat determined from these several days of observation. The fourth, the square root of the values in line 3. Thus line 3 gives the reflecting power for two mirrors, and line 4 for one mirror of stellite.

TABLE 9.—*Reflecting power of stellite mirrors.*

Prismatic deviation	240′	230′	220′	210′	200′	190′	180′	170′	160′	150′	140′	130′	120′	115′
Wave length	0.3415	0.3504	0.3600	0.3709	0.3838	0.3974	0.4127	0.4307	0.4516	0.4753	0.5026	0.5348	0.5742	0.5980
Reflection:														
Two mirrors	.268	.275	.284	.294	.304	.314	.324	.336	.350	.364	.378	.392	.406	.414
One mirror	.518	.525	.533	.542	.551	.560	.569	.580	.592	.603	.615	.626	.637	.644

Prismatic deviation	110′	105′	100′	95′	90′	85′	80′	75′	70′	65′	60′	55′	50′	45′
Wave length	0.6238	0.6530	0.6858	0.7222	0.7644	0.8130	0.8634	0.9210	0.9861	1.0692	1.1474	1.2255	1.3019	1.3800
Reflection:														
Two mirrors	.423	.432	.442	.451	.461	.469	.477	.485	.493	.502	.509	.517	.525	.532
One mirror	.650	.657	.665	.672	.679	.685	.691	.696	.702	.709	.713	.719	.725	.729

Prismatic deviation	40′	35′	30′	25′	20′	10′	0′	−10′	−20′	−30′
Wave length	1.4520	1.5285	1.6032	1.6700	1.7378	1.8700	2.0000	2.1232	2.2416	2.3481
Reflection:										
Two mirrors	.540	.547	.554	.562	.570	.588	.606	.624	.642	.660
One mirror	.735	.740	.744	.750	.755	.767	.778	.790	.801	.812

Chapter III.

PYRHELIOMETRY.

The basis of our research lies in the exactness and stability of its pyrheliometry. We are watching for changes in the radiation of the sun from day to day and from year to year. In doing so we determine the values of the intensity of solar radiation outside of the atmosphere in calories per square centimeter per minute. The accuracy of the comparisons depends, however, primarily on the exact comparability over long intervals of our observations at the earth's surface. As the bolometer (which we are obliged to use in order to determine the transparency of the earth's atmosphere) is not a standard instrument for measuring radiation, and gives merely relative values, it is necessary to standardize it against some other instrument. For this purpose we have chosen the pyrheliometer.

In our earliest investigations we proposed to employ the "black body" or perfect radiator and to determine the sensitiveness of the bolometer each day by observing with it the spectrum of the rays of such an instrument. It is fortunate that we did not do so. The experiments of many observers have shown that the use of the so-called "black body" is beset with difficulties. Neither the constants of its emission nor the technique of employing it are so thoroughly established that values accurate to 1 per cent, or even to 3 or 4 per cent, could certainly be obtained by the use of it to give a standard energy spectrum for the bolometer. Furthermore, we must reflect that the highest possible temperature of a "black body" which it would be practicable to use does not lie above one-fourth of the temperature of the sun, so that the distribution of its radiation in the spectrum, and especially the distribution for the shorter wave lengths of the spectrum, would be so different from that of the distribution of solar radiation that a high degree of accuracy would be impracticable in the comparison of the black-body radiation with the solar radiation.

The use of the pyrheliometer for the standardization of the bolometer on the contrary is very simple. It is easy to read the pyrheliometer better than to 1 per cent, and easy to read the areas of the corrected bolographs (proportional to the corresponding energy) to better than to 1 per cent. Our silver-disk pyrheliometer, which was described in Volume III of these Annals, has continued to give excellent satisfaction, not only to us, but to many others to whom standardized copies of it have been sent in many different quarters of the world. It will not be necessary to give here a description of the instrument or illustration of it, since these may be consulted by the reader in Volume III of these Annals. What is necessary is to show that the Smithsonian standard scale of pyrheliometry is reproduced by the pyrheliometers which we have employed in our regular observations, and that there has been no probability of a considerable change in our scale of measurements during the period of the solar-constant investigations which have now lasted since the year 1902, 17 years altogether.

We shall submit two lines of evidence on this point. In the first place we shall give a comparison of several secondary pyrheliometers, one with another, extending over a long period of years.[1] In the second place we shall give the results of numerous comparisons between some of these secondary pyrheliometers and the standard water-flow pyrheliometer No. 3, which was described in Volume III of these Annals.

SOURCES OF ERROR.

No change has been made for a great while in the method of reading the silver-disk pyrheliometers. However, one small source of error has been pointed out to us by Prof. Kimball, of the United States Weather Bureau, which is discussed in the following letters. It does not seem to be large enough to require attention, considering that the very small error is practically always affecting our results in the same direction, so that it is nearly eliminated in comparisons of different days.

January 31, 1916.

Dear Mr. Abbot: I am inclosing some readings made with Smithsonian silver-disk pyrheliometer No. 1 at Lincoln, Nebr. They illustrate the point I raised in conversation with you some time since relative to the best method of observing with this instrument. [These observations are here omitted.]

The point I wish to bring out is that in a series of readings which starts with low rates of cooling the value of the radiation computed from a heating plus one-half the sum of the preceding and following coolings is less than the value computed from the sum of a cooling plus one-half the sum of the preceding and following heatings. Also, this difference is not maintained in a series that continues for such a length of time that the rates of heating and cooling become nearly equal.

I wish to ask if in your opinion it is better to commence a series of readings with the temperature of the silver disk about equal to that of the air temperature, or should it be warmed up somewhat by radiation so that the heatings and coolings will be approximately equal?

I may say that in all these readings the Smithsonian instrument had been out of doors a sufficient length of time to acquire about the temperature of the air.

Very respectfully,

H. H. Kimball,
Professor of Meteorology, U. S. Weather Bureau.

February 2, 1916.

Dear Prof. Kimball: Concerning your letter of January 31, I am of the opinion that the differences you point out are due to the fact that, as stated in our paper "The Silver Disk Pyrheliometer," our abridged method of reading is an approximate one, not suitable to determine the real corrected rate of rise of temperature of the disk, as would have to be done if the attempt was made by measuring capacity for heat, etc., to use the instrument as a primary standard. The rate of rise of temperature is determined after the rise has been in progress

[1] See also Annals, Vol. III, for dates prior to 1913.

20 seconds, and the rate of fall after the fall has been in progress 20 seconds. Hence the average rate of fall of temperature is less than that suited to correct the average rate of rise. An indication of the difference of temperature between that for which the correction for cooling really applies and that at which the rate of rise is measured is found as follows:

I give first the changes of temperature which occurred in your Lincoln readings in the successive 20 second intervals ordinarily not taken into account.

	°	°	°	°	°	°	°
Between cooling and rise	0.59	0.54	0.44	0.39	0.37	0.36	0.34
Between rise and cooling	.07	.17	.21	.25	.27	.29	.30

From these I form the means indicating (A) at how much lower temperature, on the average, the coolings occurred than the intervening heating, and (B) at how much higher temperature the mean heating occurred than the intervening cooling.

A—Mean cooling temperature lower than heating	0.33°		0.355°		0.325°		0.32°		0.32°		0.325°		0.32°
B—Mean heating temperature higher than cooling		0.305°		0.305°		0.30°		0.31°		0.315°		0.315°	

It is clear from this why you find the effect noted: The upper line of figures is always in excess of the lower, but less so toward the end of the series.

I give below in abbreviated form similar values from four series of my own readings, all on Mount Wilson. I have not looked up any other series of readings:

PYRHELIOMETER:												
A. P. O. IV	A	0.26		0.28		0.27		0.27		0.255		0.255
	B		0.235		0.255		0.245		0.245		0.255	
9	A	.425		.41		.395		.405				
	B		.35		.37		.375					
9	A	.47		.42		.43		.435				
	B		.37		.375		.41					
8 *bis*	A	.37		.36		.365		.32				
	B		.295		.32		.32					

In the last two series of observations the first coolings were negative. From this and other information I conclude:

1. The constant given you with the instrument is not fairly applicable to readings reduced by the method $\frac{\text{Rise}+\text{Rise}}{2}+\text{cooling}$.

2. It would be a little better to have the instrument exposed to the sun 5 minutes before reading, as probably this will more nearly reproduce its average condition during calibration.

3. The error from employing single readings starting from slight positive or negative coolings is of the order of one-half per cent or less.

4. Fortunately the change of constant during a series seems to be generally less for readings reduced in our usual way than for series reduced in the way $\frac{\text{Rise}+\text{Rise}}{2}+\text{cooling}$.

5. It is evidently more sound to determine the reading in the usual way unless the sky is quite unchanging, for in that way one is able to state that the intensity was of a certain value at the moment when exposure to the sun was actually made. In the other method one assumes that the intensity was of such a value at a time when no exposure was actually made.

6. In 1906 Dr. Ingersoll and I conducted a long series of tests of pyrheliometers under all sorts of conditions of temperature and of change of temperature. The source of error you point out escaped us because its effect was too small to be certainly found.

7. Regarding ordinary use of silver-disk pyrheliometers, unless new comparisons are made I should think readings made some time before the rates of heating and cooling become equal would be more nearly comparable with those made when the instrument was standardized.

Yours, truly,

C. G. Abbot,
Director, Astrophysical Observatory.

Another source of error which is not always negligible lies in the eccentricity of the second hand of the observer's watch. Our definitive time intervals, according to our method of reading the silver-disk pyrheliometer, extend in each case from the 20th second to the 120th second, and therefore fall at two different points on the second-hand circle. It occurs in some watches that as much as 0.3 second, or 0.3 per cent error is introduced by eccentricity. If now, two observers, comparing two pyrheliometers, make one series with pyrheliometer A read by observer C, and pyrheliometer B read by observer D; then exchange instruments, almost 1 per cent difference between the two series of comparisons is sometimes caused by the eccentricity of their watch hands if this is neglected. Taking the mean of the two series eliminates the errors. We now always make silver-disk pyrheliometer comparisons by exchanging instruments in this way. The error may be determined for each watch, and allowed for by using some part of one of the numerals 20 or 60 stamped on the watch face, instead of the graduation lines of the 20th and 60th seconds as reference points.

INTERCOMPARISONS OF VARIOUS PYRHELIOMETERS.

The reader should compare these results with those given on pages 68 to 71 of Volume III of the Annals. It will be recalled that until July, 1920, we retained silver-disk pyrheliometers 8_{bis} and A. P. O. 9 for standardizing purposes at Washington. A. P. O. 9 was then sent to Arizona. Copper-disk pyrheliometers A. P. O. IV and A. P. O. VII were used for daily work at Mount Wilson. These two pyrheliometers are mounted on the same stand so that both may be trained upon the sun simultaneously. This duplication of pyrheliometer observations by two independent instruments greatly promotes confidence in the results. The observer reads these two instruments alternately at intervals 1 minute apart so that in the course of 7 minutes he has read both instruments, and in the course of 11 minutes has read both instruments twice. Thus, with a good clear sky he obtains on every day of observation a group of comparisons of these two instruments which, while not strictly simultaneous, are so nearly so that they may be used as giving the relative values of the constants of the two very accurately. We have selected from the high-sun observations with pyrheliometers A. P. O. IV and VII a large number of measurements to furnish comparisons of their readings for each year from 1908 to 1919.

The intercomparisons of a large number of silver-disk pyrheliometers and the constants adopted for them are included in tables given in the paper "Smithsonian Pyrheliometry Revised," by Messrs. Abbot and Aldrich.[2] We now give a continuation of the tables to cover the new instruments which have been made since, and such additional intercomparisons of the older ones as have been made in the intervening years.

From the various comparisons which have been made between silver-disk pyrheliometers A. P. O. 8_{bis} and A. P. O. 9, and others; especially from the daily comparisons which have been made between A. P. O. IV and A. P. O. VII, as well as from numerous comparisons with standard pyrheliometers; the presumption will appear very strong that the variations, if any, in the fundamental scale of our system of pyrheliometry during the long interval of the time covered by our researches on the solar radiation have been confined within 1 per cent.

In order to give a general view of this evidence of the durability of our scale of radiation we now give several long-continued series of intercomparisons of secondary pyrheliometers, as well as the standardizations which have been made from time to time on copper-disk pyrheliometer A. P. O. IV on Mount Wilson against the standard water-flow pyrheliometer No. 3 which was described in Volume III of the Annals. We include in the following table not only the work of the last six years but also the earlier standardizations which were reported in Volume III of the Annals.

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[2] Smithsonian Miscellaneous Collections, vol. 60, no. 18, 1913.

TABLE 10.—*Comparisons of pyrheliometers, 1913 to 1920.*

Date.	Number of comparisons.	Secondaries used.		Ratio $\frac{A}{B}$	Probable error.	Remarks.
		A.	B.			
Jan. 28, 1913	11	S. I. No. 1	A. P. O. No. 8_{bis}	1.0349	0.0029	
Jan. 28, 1913	10	S. I. No. 1	A. P. O. No. 8_{bis}	1.0324	.0027	
Mar. 22, 1915	6	S. I. No. 1	A. P. O. No. 8_{bis}	1.0343	.0035	
Feb. 14, 1916	6	S. I. No. 1	A. P. O. No. 8_{bis}	1.0119	.0017	
Feb. 13, 1917	9	S. I. No. 1	A. P. O. No. 8_{bis}	1.0360	.0031	
Nov. 5, 1917	5	S. I. No. 1	A. P. O. No. 8_{bis}	1.0330	.0036	
Apr. 6, 1914	15	S. I. No. 1	A. P. O. No. 9	.9870	.0020	
Mar. 22, 1915	6	S. I. No. 1	A. P. O. No. 9	.9878	.0027	
Mar. 31, 1916	12	S. I. No. 1	A. P. O. No. 9	.9946	.0019	
Mar. 12, 1919	8	S. I. No. 17	A. P. O. No. 8_{bis}	1.0488	.0012	New thermometer
Mar. 12, 1919	7	S. I. No. 17	A. P. O. No. 9	.9941	.0023	February, 1919.
Apr. 19, 1919	6	S. I. No. 17	A. P. O. No. 9	.9996	.0004	
Jan. 28, 1913	12	S. I. No. 18	A. P. O. No. 8_{bis}	1.0046	.0013	
Jan. 30, 1913	8	S. I. No. 18	A. P. O. No. 8_{bis}	.9977	.0022	
Feb. 1, 1913	7	S. I. No. 18	A. P. O. No. 8_{bis}	1.0070	.0024	
Apr. 30, 1913	16	S. I. No. 19	A. P. O. No. 8_{bis}	1.0132	.0016	
April and May, 1913	25	S. I. No. 20	A. P. O. No. 8_{bis}	1.0243	.0018	
Mar. 12, 1919	8	S. I. No. 20	A. P. O. No. 9	.9894	.0018	New mercury
Mar. 12, 1919	7	S. I. No. 20	A. P. O. No. 8_{bis}	1.0343	.0015	around bulb of
Apr. 19, 1919	6	S. I. No. 20	A. P. O. No. 8_{bis}	1.0352	.0032	thermometer S.
May 3, 1913	12	S. I. No. 21	A. P. O. No. 8_{bis}	1.0202	.0013	I. No. 20.
June 9, 1913	16	S. I. No. 22	A. P. O. No. 8_{bis}	1.0021	.0011	
Jan. 14, 1914	21	S. I. No. 23	A. P. O. No. 8_{bis}	1.0281	.0018	
Feb. 21, 1914	13	S. I. No. 24	A. P. O. No. 8_{bis}	1.0195	.0014	
Feb. 21, 1914	15	S. I. No. 25	A. P. O. No. 8_{bis}	1.0186	.0015	
June 2, 1914	10	S. I. No. 26	A. P. O. No. 8_{bis}	1.0531	.0026	
June 3, 1914	6	S. I. No. 26	A. P. O. No. 8_{bis}	1.0551	.0023	
Mar. 29, 1915	6	S. I. No. 27	A. P. O. No. 9	.9855	.0019	
Mar. 29, 1915	7	S. I. No. 27	A. P. O. No. 9	.9882	.0019	
June 11, 1915	6	S. I. No. 27	A. P. O. No. IV	1.3993	.0013	
June 26, 1915	4	S. I. No. 27	A. P. O. No. IV	1.3822	.0053	
Nov. 30, 1915	8	S. I. No. 28	A. P. O. No. 8_{bis}	1.0422	.0019	
Dec. 7, 1915	4	S. I. No. 28	A. P. O. No. 8_{bis}	1.0401	.0063	
Dec. 15, 1915	8	S. I. No. 28	A. P. O. No. 8_{bis}	1.0391	.0007	
Nov. 7, 1916	5	S. I. No. 29	A. P. O. No. 8_{bis}	[1] 1.0417	.0012	
Feb. 10, 1917	10	S. I. No. 29	A. P. O. No. 8_{bis}	[1] 1.0453	.0019	
May 2, 1918	19	S. I. No. 29	A. P. O. No. 8_{bis}	[1] 1.0310	.0014	
May 7, 1918	17	S. I. No. 29	A. P. O. No. 8_{bis}	[1] 1.0372	.0021	
Nov. 7, 1916	5	S. I. No. 30	A. P. O. No. 8_{bis}	1.0407	.0030	
Feb. 10, 1917	10	S. I. No. 30	A. P. O. No. 9	1.0117	.0020	
July 10, 1917 to Mar. 18, 1918.	20	S. I. No. 30	S. I. No. 29	1.0065	.0013	
May 6 and 10, 1920.	9	S. I. No. 31	A. P. O. No. 8_{bis}	.9870	.0016	
Aug. 27 to Sept. 1, 1920.	22	S. I. No. 32	A. P. O. No. VII	1.3841	.0020	
Oct. 2 to Oct. 9, 1920	12	S. I. No. 32	A. P. O. No. 9	1.0285	.0015	

[1] Mean 1.030.

TABLE 11.—*Various A. P. O. pyrheliometers.*

Date.	Number of comparisons.	Secondaries used.		Ratio $\frac{A}{B}$	Probable error.	Remarks.
		A.	B.			
Aug. 21, 1914	6	A. P. O. 9	A. P. O. IV	1.4127	0.0048	
Sept. 20, 1914	9	A. P. O. 9	A. P. O. IV	1.3964	.0025	
May 12, 1913	9	A. P. O. 9	A. P. O. 8_{bis}	1.0449	.0019	
May 31, 1913	16	A. P. O. 9	A. P. O. 8_{bis}	1.0429	.0014	
Mar. 22, 1915	7	A. P. O. 9	A. P. O. 8_{bis}	1.0490	.0020	
Feb. 10, 1917	10	A. P. O. 9	A. P. O. 8_{bis}	1.0345	.0023	Readings 1 minute apart.
Feb. 13, 1917	10	A. P. O. 9	A. P. O. 8_{bis}	1.0396	.0019	
May 6, 1918	8	A. P. O. 9	A. P. O. 8_{bis}	1.0486	.0023	
Mar. 12, 1919	8	A. P. O. 9	A. P. O. 8_{bis}	1.0503	....	Through S. I. 17 and S. I. 20.
Aug. 27 to Sept. 1, 1920	22	A. P. O. 9	A. P. O. IV	1.3841	.0022	
July–Aug., 1920	36	A. P. O. IV	A. P. O. VII	.9872	.0006	

TABLE 12.—*Comparisons with standard pyrheliometer No. 3.*

Date.	Number of comparisons.	Standard used.	Secondary used.	Standard / Secondary.	Probable error.
Sept. 15, 1915	9	No. 3	A. P. O. IV	0.5141	0.0023
Sept. 15, 1915	9	No. 3	A. P. O. VII	.5056	.0017
Sept. 19, 1915	6	No. 3	A. P. O. IV	.5100	.0019
Sept. 19, 1915	5	No. 3	A. P. O. VII	.5007	.0021
Sept. 21, 1915	4	No. 3	A. P. O. IV	.5084	.0020
Sept. 21, 1915	4	No. 3	A. P. O. VII	.4983	.0016
July 7, 1916	4	No. 3	A. P. O. IV	.5119	.0012
July 10, 1916	11	No. 3	A. P. O. IV	.5111	.0024
Sept. 2, 1916	6	No. 3	A. P. O. IV	.5135	.0031
Aug. 29, 1920	7	No. 3	A. P. O. IV	.5111	.0022
Aug. 30, 1920	12	No. 3	A. P. O. 9	.3606	.0010
Aug. 30, 1920	11	No. 3	S. I. 32	.3691	.0007

TABLE 13.—*Recovery of test quantities of heat by standard pyrheliometer No. 3.*

Pyrheliometer.	Date.	Number of tests.	Heat recovered.	Average deviation.	Remarks.
			Per cent.	*Per cent.*	
Standard Water Flow No. 3	July 10, 1916	9	98.2	2.1	All determinations.
Do	July 10, 1916	7	99.6	0.9	Omitting first two.
Do	Aug. 31, 1920	10	99.67	0.38	

TABLE 14.—*Present adopted constants of silver disk pyrheliometers, Smithsonian Revised Pyrheliometry of 1913.*

Instrument.	Constant.[1]	Where sent.
S. I. 1	0.3683	U. S. Weather Bureau.
S. I. 2	0.3734	(1) Rykacev, Russia; (2) Observatory, Rio Janeiro, Brazil.
S. I. 3	0.3625	Violle, Paris, France.
S. I. 4	0.3713	Chistoni, Naples, Italy.
S. I. 5	0.3672	U. S. Department of Agriculture, Physical Laboratory.
S. I. 6	0.3666	Oficina Meteor., Buenos Aires, Argentina.
S. I. 7	0.3638	Do.
S. I. 8	0.3774	Central Observatory, Madrid, Spain.
S. I. 9	0.3737	Imp. Coll. Science and Technology, London, England.
S. I. 10	0.3762	K. Preuss. Meteor. Institut, Berlin, Germany.
S. I. 11	0.3769	Meteor. Observatory, Teneriffe, Canary Islands.
S. I. 12	0.3631	K. Preuss. Meteor. Institut, Berlin, Germany.
S. I. 13	0.3617	Meteor. Centralanstalt, Zurich, Switzerland.
S. I. 14	0.3714	University, Toronto, Canada.
S. I. 15	0.3609	U. S. National Bureau Standards.
S. I. 16	0.3657	University of Arizona, Tuscon.
S. I. 17	0.3635	Harvard Coll. Observatory, Arequipa, Peru.
S. I. 17	0.3632	Original thermometer broken. Repaired and taken to Calama, Chile, May, 1919.
S. I. 18	0.3774	Observatorio Nacional, Rio de Janeiro, Brazil.
S. I. 19	0.3737	Aeronautisches Observatorium, Lindenberg, Germany.
S. I. 20	0.3690	Loaned to Italian Indo-Asiatic expedition. Returned to Washington, July, 1916, and new mercury inserted.
S. I. 21	0.3711	Aeronautisches Observatorium, Lindenberg, Germany.
S. I. 22	0.3778	Observatorio Astronomico Nacional, Tacubaya, Mexico.
S. I. 23	0.3683	Landwirtschaftlichen Institut, Moskau, Russia.
S. I. 24	0.3713	Meteor. Observatory, Teneriffe, Canary Islands.
S. I. 25	0.3717	Do.
S. I. 26	0.3592	Kon. Magnetischen Meteorologisch Observatorium, Batavia, Java.
S. I. 27	0.3679	Manila Observatory, Manila, P. I.
S. I. 28	0.3639	Meteorological Office, London, England.
S. I. 29	0.3626	Calama, Chile, Smithsonian South American expedition.
S. I. 30	0.3605	Do.
S. I. 31	0.3836	Edgewater, Colorado, Dr. M. J. Marshak.
S. I. 32	0.3691	Mount Harqua Hala, Arizona, Smithsonian Astrophysical Observatory.

VARIOUS A. P. O. INSTRUMENTS.

A. P. O. IV	0.5118	Mount Wilson, Calif.
A. P. O. VII	0.5072	Do.
A. P. O. VIII	0.5150	(1) U. S. Weather Bureau; (2) Mount Wilson.
A. P. O. 8	0.3760	Washington and Mount Wilson.
A. P. O. 8_{bis}	0.3786	Do.
A. P. O. 9	0.3631	Washington, Mount Wilson, Mount Whitney, Algeria, Arizona.

[1] These values are the factors by which the corrected temperature rise in 100 seconds is to be multiplied to reduce the readings to calories (15° C) per square centimeter per minute.

TABLE 15.—*Long-continued series of intercomparisons of pyrheliometers.*

S. I. 1 WITH A. P. O. 8_{bis}.

Year	1911	1911	1912	1913	1915	[1] 1916	1917	1917
Ratio	1.0357	1.0246	1.0268	1.0324	1.0343	1.0119	1.0360	1.0330

A. P. O. 9 WITH A. P. O. 8_{bis}.

Year	1911	1912	1912	1912	1913	1913	1915	1917	1917	1918	[2] 1919
Ratio	1.0469	1.0328	1.0470	1.0445	1.0449	1.0429	1.0490	1.0345	1.0396	1.0486	1.0503

A. P. O. 9 WITH A. P. O. IV.

Year	1910	1911	1914	1914	1920
Ratio	1.3820	1.4102	1.4127	1.3964	1.3841

A. P. O. 8_{bis} WITH A. P. O. IV.

Year	[3] 1906	[3] 1908	1911	[4] 1914	[5] 1915
Ratio	1.335	1.357	1.352	1.347	1.352

A. P. O. IV WITH A. P. O. VII.

Year	1908	1909	1910	1912	1913	1914	1915	1916	1917	1918	1919	1920
Ratio	0.9905	0.9955	0.9892	0.9892	0.9861	0.9840	0.9851	0.9842	0.9858	0.9840	0.9854	0.9872

STANDARD 3 WITH A. P. O. IV.

Year	[6] 1910	1911	[6] 1915	[6] 1916	1920
Ratio	0.5149	0.5094	0.5108	0.5122	0.5111

[1] It is believed that owing to maladjustment S. I. 1 was not properly exposed.

[2] Indirect through S. I. 17 and S. I. 20.

[3] Through A. P. O. V, assuming $\frac{\text{A. P. O. V.}}{\text{A. P. O. } 8_{bis}}=0.795$.

[4] Through A. P. O. 9, assuming $\frac{\text{A. P. O. 9}}{\text{A. P. O. } 8_{bis}}=1.0426$.

[5] Through A. P. O. 9 and S. I. 27, assuming $\frac{\text{S. I. 27}}{\text{A. P. O. 9}}=0.987$ and $\frac{\text{S. I. 27}}{\text{A. P. O. IV}}=1.391$.

[6] Mean of several days' comparisons.

Chapter IV.

RESULTS OF MEASUREMENTS OF THE INTENSITY OF SOLAR RADIATION.

In Volumes II and III of these Annals have been given the details of the means and methods adopted and the degree of accuracy to be expected in our measurements of the intensity of solar radiation. In preceding chapters of the present volume have been detailed such modifications of the methods and apparatus as have been introduced since the publication of Volume III of the Annals. The present chapter will be devoted to setting forth the numerical results obtained at Mount Wilson, California, Hump Mountain, North Carolina, and Calama, Chile, in the years 1912 to 1920, inclusive. The results are given in terms of the standard scale of pyrheliometry fully established by us in the year 1913 and which has been maintained to the present by the system of comparisons of pyrheliometers, both standard and secondary, which has been described in the preceding chapter.

The aim of the investigation, as heretofore, is to determine the mean intensity of the solar radiation which reaches the planet Earth, the variation of the intensity depending upon changes of the solar emission and the alteration in quality and quantity to which the solar radiation is subject during its passage through the atmosphere toward the soil, apart from the obstruction offered by visible clouds. The method of investigation which has been almost exclusively adopted comprises measurements of the total intensity of the solar beam as it reaches the earth's surface combined with other measurements adapted to enable us to estimate the losses which occur in the atmosphere. In a confirmatory investigation entitled "New Evidence on the Intensity of the Solar Radiation Outside the Atmosphere," which is reprinted in Appendix I, we have given very strong proofs of the soundness and accuracy of this method as we have employed it, and confirmatory evidence of the accuracy of the result. This we obtained by constructing special autographic pyrheliometers which were raised by sounding balloons to about 25 km altitude, where the pressure of the atmosphere is reduced to $\frac{1}{25}$ of its value at the earth's surface. The radiation intensity found at this great altitude was 1.84 calories per square centimeter per minute. Allowing 2 per cent additional as the diminution of the intensity of the beam in passing through the atmosphere above this level, we reached the value of 1.88 calories per square centimeter per minute by this confirmatory method. This value, as the reader will see, lies within the range of values which we have obtained by the usual procedure and within the range of variation which we attribute to the sun.

Our usual investigations are carried out by the aid of the pyrheliometer and the spectrobolometer, and nearly all the determinations to be given in the present chapter of the intensity of the solar radiation outside the atmosphere, or the "solar constant of radiation," so called, are computed with the combined results of measurements with these two instruments. Results have been obtained very recently at Calama, Chile, by the new empirical process involving the use of the pyranometer, as has been hitherto described. The method of making and computing the measurements in the usual manner is given in the description, syllabus, and illustrative examples which form Chapter I of Volume III of the Annals. Further information in regard to it will be found in the first part of the paper in Appendix I of the present volume to which reference has just been given.

PYRHELIOMETER MEASUREMENTS.

In the following tables are included all the most important pyrheliometer observations made at Mount Wilson, California, Hump Mountain, North Carolina, and Calama, Chile, since 1912.[1] For the Mount Wilson observations, the initials of the observer and the designation of the instrument employed are indicated for each day of observation. The observations are given in two columns, of which the first contains the air mass, which is nearly the same as the secant of zenith distance, but for which we employ the corrections determined by Bemporad, which somewhat diminish the values exceeding 2 air masses. The second column contains the corrected reading of the rise of temperature of the pyrheliometer. These corrected readings have not been reduced to calories per square centimeter per minute, because in transcribing the great number of observations it would be more difficult to avoid mistakes if in addition to transcribing them they should each be multiplied by the proper constant. It has been supposed, moreover, that only a few of the readings would be employed by other investigators at such special epochs as their studies might require. The value of the constant is given at the bottom of each page of observations and is adapted to reduce the readings to calories per square centimeter per minute on the basis of "Smithsonian Revised Pyrheliometry of 1913."

[1] To save space we have omitted the readings of pyrheliometer VII at Mount Wilson and of pyrheliometer 29 at Hump Mountain and Calama. These instruments are always read alternately with pyrheliometers IV and 30, respectively, at the stated stations, and as their readings are nearly identical with those of Nos. IV and 30, which are here given, no useful information is added by publishing them.

TABLE 16.—*Pyrheliometer readings, Mount Wilson, California, 1912.*

[Pyrheliometer A. P. O. IV[1]—Observer F. E. F.]

M.	R.
Apr. 27, a. m.	
3.645	1.368
3.470	1.403
2.522	1.553
2.443	1.547
1.992	1.697
1.944	1.647
1.680	1.703
1.648	1.694
1.388	1.742
1.372	1.754
1.172	1.774
1.164	1.766
May 1, a. m.	
2.754	1.408
2.657	1.394
2.246	1.457
2.180	1.475
1.863	1.554
1.823	1.544
1.619	1.582
1.591	1.582
May 2, a. m.	
3.354	1.273
3.207	1.324
2.592	1.438
2.506	1.503
1.910	1.591
1.865	1.606
1.611	1.667
1.583	1.664
1.369	1.720
1.351	1.742
May 3, a. m.	
3.762	1.427
3.570	1.447
2.821	1.555
2.713	1.555
2.222	1.619
2.160	1.646
1.788	1.709
1.751	1.702
1.430	1.770
1.410	1.789
1.207	1.816
1.198	1.821
May 4, a. m.	
3.816	1.192
2.913	1.374
2.800	1.381
2.291	1.472
2.226	1.505
1.936	1.570
1.893	1.569
1.558	1.658
1.530	1.660

M.	R.
May 4, a. m.	
1.290	1.743
1.274	1.755
May 5, a. m.	
3.830	1.151
3.636	1.149
2.890	1.297
2.780	1.307
2.343	1.433
2.272	1.445
1.939	1.536
1.895	1.537
1.553	1.615
1.528	1.627
1.308	1.676
1.292	1.669
May 10, a. m.	
4.060	1.197
3.850	1.210
3.050	1.347
2.930	1.368
2.285	1.478
2.220	1.500
1.930	1.563
1.885	1.541
1.582	1.626
1.558	1.631
1.335	1.675
1.320	1.699
May 11, a. m.	
3.722	1.278
3.550	1.299
2.865	1.409
2.758	1.410
2.245	1.503
2.182	1.513
1.893	1.570
1.850	1.581
1.552	1.647
1.528	1.662
1.282	1.697
1.266	1.705
May 12, a. m.	
3.645	1.165
3.472	1.199
2.839	1.292
2.735	1.307
2.253	1.405
2.190	1.424
1.936	1.482
1.890	1.498
1.598	1.569
1.570	1.583
1.336	1.625
1.320	1.643

M.	R.
May 13, a. m.	
3.625	1.192
3.450	1.214
2.652	1.372
2.562	1.367
2.138	1.470
2.080	1.486
1.913	1.538
1.775	1.571
1.535	1.615
1.507	1.609
1.301	1.621
1.285	1.681
May 14, a. m.	
3.588	1.198
3.419	1.217
2.805	1.322
2.703	1.334
2.285	1.426
2.220	1.445
1.924	1.504
1.880	1.511
1.583	1.585
1.555	1.584
1.372	1.633
1.356	1.647
May 15, a. m.	
2.230	1.402
2.165	1.433
1.910	1.505
1.865	1.516
1.670	1.566
1.635	1.558
1.499	1.594
1.472	1.593
1.332	1.660
1.318	1.653
1.200	1.674
1.190	1.662
May 20, a. m.	
2.995	1.339
2.878	1.347
2.381	1.457
2.310	1.446
1.944	1.533
1.897	1.541
1.697	1.593
1.664	1.567
1.441	1.670
1.420	1.651
1.266	1.694
1.253	1.700
May 22, a. m.	
3.336	1.242
3.190	1.263
2.652	1.349

M.	R.
May 22, a. m.	
2.563	1.365
2.155	1.434
2.098	1.452
1.835	1.492
1.795	1.503
1.522	1.549
1.498	1.571
1.350	1.565
1.334	1.600
May 23, a. m.	
3.393	1.248
2.760	1.365
2.345	1.443
2.030	1.513
1.977	1.510
1.731	1.584
1.544	1.621
1.520	1.630
May 28, a. m.	
3.712	1.345
3.531	1.376
2.921	1.450
2.431	1.527
2.358	1.538
2.065	1.576
1.775	1.650
1.533	1.685
1.506	1.675
May 30, a. m.	
3.924	1.396
3.722	1.429
3.022	1.486
2.517	1.579
2.140	1.628
1.820	1.697
1.534	1.734
1.510	1.754
May 31, a. m.	
2.391	1.576
2.321	1.591
1.966	1.651
1.714	1.694
1.569	1.699
1.404	1.732
1.252	1.782
1.238	1.783
June 1, a. m.	
3.360	1.415
3.214	1.438
2.700	1.500
2.608	1.453
2.233	1.587
1.935	1.624

M.	R.
June 1, a. m.	
1.667	1.681
1.440	1.717
1.420	1.714
June 1, p. m.	
1.430	1.481
1.582	1.493
1.879	1.430
2.116	1.398
2.440	1.274
2.871	1.217
June 2, a. m.	
3.548	1.357
3.388	1.372
2.815	1.449
2.400	1.537
2.058	1.599
2.006	1.598
1.675	1.669
1.367	1.724
1.348	1.729
June 3, a. m.	
3.131	1.391
3.003	1.434
2.491	1.514
2.135	1.555
1.865	1.627
1.627	1.654
1.380	1.722
June 3, p. m.	
1.456	1.620
1.480	1.639
1.642	1.613
1.835	1.556
2.053	1.520
2.357	1.466
2.736	1.355
2.833	1.360
June 4, a. m.	
3.245	1.434
2.608	1.515
2.230	1.545
2.170	1.550
1.925	1.600
1.652	1.646
1.418	1.694
1.398	1.697
June 5, a. m.	
3.386	1.382
2.789	1.479
2.293	1.554
2.229	1.552

M.	R.
June 5, a. m.	
1.969	1.614
1.771	1.622
1.421	1.676
1.401	1.689
June 6, a. m.	
3.266	1.362
3.132	1.385
2.554	1.460
2.210	1.512
1.942	1.558
1.606	1.632
1.578	1.634
1.355	1.686
1.339	1.708
June 7, a. m.	
3.488	1.436
3.331	1.477
2.779	1.549
2.353	1.600
2.078	1.655
1.729	1.710
1.439	1.759
1.417	1.745
June 7, p. m.	
1.433	1.707
1.559	1.690
1.775	1.644
1.963	1.628
2.318	1.567
2.705	1.510
2.804	1.502
June 8, a. m.	
3.284	1.390
3.148	1.435
2.651	1.487
2.562	1.511
2.170	1.579
1.936	1.617
1.636	1.649
1.607	1.657
1.333	1.709
1.317	1.706
June 9, a. m.	
3.544	1.379
3.386	1.404
2.821	1.470
2.400	1.524
2.112	1.564
1.770	1.641
1.409	1.699
1.389	1.707

M.	R.
June 10, a. m.	
3.385	1.274
3.240	1.286
2.495	1.417
2.140	1.479
1.810	1.553
1.584	1.608
1.324	1.643
1.308	1.661
June 11, a. m.	
3.493	1.236
3.336	1.287
2.761	1.352
2.358	1.422
2.005	1.499
1.634	1.575
1.335	1.607
1.319	1.661
June 13, p. m.	
1.525	1.625
1.720	1.620
1.941	1.571
2.190	1.494
2.522	1.467
2.972	1.406
June 14, a. m.	
3.475	1.421
3.324	1.438
2.774	1.512
2.231	1.579
1.986	1.635
1.938	1.655
1.593	1.714
1.565	1.695
1.340	1.774
1.324	1.759
June 15, a. m.	
3.250	1.485
3.116	1.505
2.476	1.571
2.155	1.626
1.862	1.695
1.505	1.743
1.248	1.801
1.235	1.813
June 16, a. m.	
3.169	1.387
2.621	1.457
2.210	1.523
1.912	1.593
1.604	1.661
1.250	1.750
1.237	1.720

[1] To reduce readings of Pyrheliometer A. P. O. IV to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.853.

TABLE 16.—*Pyrheliometer readings, Mount Wilson, California, 1912*—Continued.

M.	R.
June 17, a. m.	
3.106	1.424
2.986	1.467
2.492	1.540
2.415	1.532
2.110	1.587
1.825	1.654
1.498	1.695
1.475	1.698
1.207	1.768
1.195	1.753
June 18, a. m.	
3.169	1.468
3.045	1.492
2.555	1.547
2.180	1.615
2.125	1.612
1.846	1.675
1.555	1.729
1.260	1.775
1.247	1.796
June 19, a. m.	
3.137	1.412
3.015	1.430
2.554	1.503
2.210	1.553
1.926	1.616
1.508	1.698
1.484	1.682
1.231	1.742
1.219	1.737
June 20, a. m.	
3.169	1.420
3.045	1.455
2.555	1.504
2.166	1.576
2.112	1.582
1.768	1.642
1.526	1.697
1.238	1.735
1.226	1.729
June 25, a. m.	
2.195	1.527
1.948	1.572
1.744	1.604
1.570	1.624
1.385	1.698
1.209	1.737
June 25, p. m.	
1.460	1.677
1.583	1.671
1.769	1.620
1.994	1.603
2.328	1.541
2.742	1.465
June 26, a. m.	
3.271	1.459
2.668	1.512
2.242	1.574
1.870	1.642
1.562	1.717
1.235	1.745
1.223	1.748
June 27, a. m.	
3.397	1.393
2.748	1.495
2.348	1.548
1.998	1.624
1.632	1.684
1.600	1.669
1.298	1.734
1.282	1.758
June 30, a. m.	
2.729	1.239
2.354	1.329
2.065	1.411
1.820	1.473
1.780	1.460
1.509	1.536
1.270	1.597
1.255	1.602
July 1, a. m.	
2.742	1.332
2.641	1.354
2.291	1.438
2.000	1.456
1.783	1.486
1.502	1.529
July 4, a. m.	
3.065	1.032
2.955	1.072
2.522	1.152
2.213	1.209
1.887	1.304
1.536	1.410
1.304	1.485
1.292	1.505
July 5, a. m.	
3.390	1.246
3.235	1.248
2.702	1.362
2.255	1.436
1.957	1.503
1.559	1.592
1.260	1.683
July 5, p. m.	
1.408	1.539
1.579	1.499
July 5, p. m.	
1.730	1.444
1.909	1.408
2.175	1.348
2.503	1.303
July 6, a. m.	
2.388	1.302
2.109	1.382
1.863	1.425
1.688	1.484
1.460	1.537
1.436	1.572
1.275	1.632
July 7, a. m.	
3.440	1.129
2.820	1.249
2.381	1.316
2.048	1.387
1.579	1.536
1.273	1.606
1.049	1.656
July 8, a. m.	
2.965	1.240
2.503	1.365
2.425	1.335
2.073	1.406
1.859	1.463
1.493	1.558
1.247	1.595
1.051	1.651
July 9, a. m.	
1.908	1.473
1.860	1.515
1.668	1.569
1.528	1.583
1.388	1.611
1.219	1.661
1.207	1.636
1.050	1.713
July 11, a. m.	
2.127	1.325
1.902	1.377
1.703	1.411
1.518	1.443
1.368	1.518
1.204	1.557
1.193	1.577
1.052	1.622
July 12, a. m.	
3.250	1.250
2.730	1.324
2.344	1.400
1.890	1.488
July 12, a. m.	
1.575	1.554
1.250	1.641
1.057	1.673
July 12, p. m.	
1.379	1.571
1.513	1.536
1.691	1.485
1.880	1.426
2.122	1.345
2.550	1.254
2.635	1.231
July 13, a. m.	
3.060	1.054
2.970	1.079
2.521	1.180
2.150	1.273
1.775	1.358
1.502	1.451
1.232	1.518
1.034	1.563
July 14, a. m.	
2.960	1.185
2.501	1.269
2.102	1.371
1.779	1.431
1.481	1.519
1.229	1.583
1.050	1.657
July 19, a. m.	
2.840	1.077
2.740	1.092
2.366	1.184
2.072	1.275
1.813	1.348
1.467	1.451
1.213	1.515
1.034	1.559
July 19, p. m.	
1.420	1.518
1.442	1.494
1.591	1.461
1.770	1.408
1.955	1.355
2.229	1.312
2.623	1.231
July 20, a. m.	
2.920	1.184
2.471	1.283
2.138	1.337
1.791	1.446
1.410	1.547
1.190	1.599
1.052	1.639
July 20, p. m.	
1.370	1.533
1.543	1.495
1.713	1.437
1.882	1.384
2.138	1.315
2.433	1.248
2.848	1.186
July 21, a. m.	
2.663	1.251
2.306	1.313
2.019	1.370
1.720	1.434
1.410	1.528
1.197	1.564
1.055	1.614
July 22, a. m.	
2.758	1.181
2.355	1.262
2.023	1.373
1.787	1.393
1.513	1.475
1.213	1.566
1.043	1.599
July 23, a. m.	
2.713	1.284
2.341	1.377
2.097	1.438
1.723	1.511
1.497	1.591
1.217	1.653
1.206	1.667
1.045	1.670
July 23, p. m.	
1.429	1.565
1.603	1.563
1.785	1.483
1.981	1.437
2.245	1.396
2.561	1.336
July 25, a. m.	
2.900	1.214
2.398	1.295
2.081	1.373
1.851	1.444
1.550	1.527
1.286	1.585
1.052	1.665
July 26 a. m.	
2.769	1.080
2.360	1.194
2.066	1.276
1.802	1.349
July 26, a. m.	
1.567	1.423
1.051	1.566
July 27, a. m.	
2.068	1.353
1.853	1.395
1.653	1.450
1.520	1.481
1.329	1.553
1.189	1.575
1.062	1.590
July 31, a. m.	
2.940	0.896
2.470	1.015
2.113	1.103
1.843	1.166
1.528	1.284
1.061	1.487
July 31, p. m.	
1.455	1.209
1.644	1.084
1.833	1.033
2.033	0.954
2.318	0.768
2.391	0.787
Aug. 1, a. m.	
2.850	0.947
2.417	1.066
2.108	1.130
1.782	1.252
Aug. 2, a. m.	
2.788	1.105
2.372	1.231
2.042	1.413
1.772	1.583
1.478	1.729
1.200	1.933
1.057	2.188
Aug. 3, a. m.	
3.005	1.008
2.524	1.106
2.153	1.199
1.825	1.300
1.484	1.408
1.251	1.486
1.068	1.517
Aug. 4, a. m.	
2.305	1.171
2.041	1.251
1.810	1.308
Aug. 4, a. m.	
1.590	1.370
1.423	1.423
1.231	1.497
1.069	1.559
Aug. 5, a. m.	
3.245	1.021
2.708	1.144
2.244	1.244
1.887	1.330
1.604	1.413
1.292	1.510
1.065	1.591
Aug. 6, a. m.	
2.945	1.084
2.452	1.184
2.097	1.282
1.804	1.380
1.498	1.443
1.275	1.513
1.064	1.591
Aug. 7, a. m.	
2.976	1.085
2.509	1.103
1.830	1.363
1.522	1.457
1.270	1.532
1.072	1.583
Aug. 8, a. m.	
3.000	1.119
2.525	1.219
2.160	1.313
1.820	1.401
1.520	1.482
1.283	1.563
1.070	1.631
Aug. 9, a. m.	
3.045	1.184
2.568	1.296
2.170	1.367
1.835	1.451
1.545	1.499
1.293	1.578
1.060	1.608
Aug. 10, a. m.	
3.040	0.820
2.535	0.937
2.182	1.067
1.844	1.169
1.545	1.278
1.300	1.367
1.072	1.445

TABLE 16.—*Pyrheliometer readings, Mount Wilson, California, 1912*—Continued.

M.	R.
Aug. 11, a. m.	
3.021	1.073
2.545	1.179
2.175	1.263
1.848	1.367
1.547	1.423
1.304	1.488
1.079	1.554
Aug. 12, a. m.	
3.075	1.033
2.570	1.153
2.202	1.241
1.836	1.334
1.556	1.386
1.287	1.488
1.079	1.550
Aug. 13, a. m.	
3.065	0.973
2.560	1.086
2.172	1.187
1.853	1.287
1.560	1.382
1.289	1.460
1.070	1.543

M.	R.
Aug. 14, a. m.	
3.107	1.081
2.610	1.173
2.217	1.283
1.865	1.388
1.540	1.472
1.294	1.539
1.077	1.615
Aug. 17, a. m.	
3.015	0.890
2,539	1.025
2.163	1.097
1.912	1.239
1.620	1.315
1.080	1.530
Aug. 18, a. m .	
3.175	0.999
2.575	1.133
2.256	1.195
1.897	1.288
1.587	1.357
1.306	1.464
1.082	1.438

M.	R.
Aug. 19, a. m.	
3.200	0.856
2.633	0.970
2.240	1.085
1.907	1.208
1.595	1.332
1.312	1.416
1.076	1.517
Aug. 20, a. m.	
3.237	0.919
2.615	1.031
2.261	1.104
1.919	1.239
1.603	1.326
1.318	1.450
1.099	1.536
Aug. 21, a. m.	
3.240	1.046
2.625	1.183
2.256	1.275
1.917	1.365
1.600	1.470
1.313	1.554
1.093	1.640

M.	R.
Aug. 22, a. m.	
3.300	1.131
2.670	1.246
2.289	1.323
1.943	1.401
1.620	1.483
1.327	1.577
1.098	1.652
Aug. 23, a. m.	
2.745	1.189
2.278	1.277
1.950	1.384
1.638	1.435
1.338	1.523
1.088	1.593
Aug. 25, a. m.	
3.362	0.929
2.794	1.055
2.318	1.153
2.023	1.205
1.115	1.517

M.	R.
Aug. 26, a. m.	
3.393	0.890
2.760	1.022
2.318	1.116
1.114	1.516
Aug. 27, a. m.	
3.433	1.148
2.708	1.275
2.332	1.355
1.983	1.429
1.686	1.483
1.365	1.581
1.112	1.685
Aug. 28, a. m.	
3.433	1.199
2.813	1.295
2.329	1.384
1.980	1.480
1.687	1.502
Aug. 29, a. m.	
3.475	1.081
2.867	1.191

M.	R.
Aug. 29, a. m.	
2.390	1.297
1.915	1.403
Aug. 30, a. m.	
3.502	1.021
2.885	1.110
2.425	1.207
2.005	1.317
1.702	1.381
1.384	1.453
1.120	1.450
Sept. 1, a. m.	
3.585	0.917
2.925	1.031
2.475	1.130
2.040	1.271
1.712	1.363
1.411	1.458
Sept. 2, a. m.	
3.588	0.998
2.896	1.111
2.377	1.235
2.010	1.315

M.	R.
Sept. 2, a. m.	
1.400	1.512
1.134	1.610
Sept. 3, a. m.	
3.505	0.939
2.871	1.057
2.415	1.132
2.096	1.221
Sept. 4, a. m.	
3.455	0.674
2.800	0.795
2.362	0.938
2.028	1.034
1.717	1.048
Sept. 5, a. m.	
3.458	0.872
2.794	1.017
2.380	1.122
2.057	1.226
1.631	1.355
1.381	1.466
1.133	1.566

TABLE 17.—*Pyrheliometer readings, Mount Wilson, California, 1913.*

[Pyrheliometer A. P. O. IV[1]—Observers, C. G. A. and L. B. A.]

M.	R.
July 16, a. m.[2]	
3.543	1.134
2.867	1.239
2.225	1.368
1.803	1.465
1.484	1.542
1.241	1.616
July 23, a. m.[2]	
3.880	1.128
3.079	1.244
2.435	1.356
1.928	1.489
July 24, a. m.[2]	
3.906	1.145
3.093	1.244
2.444	1.349
1.969	1.449
1.575	1.522
1.547	1.543
1.246	1.623
1.234	1.644

M.	R.
Aug. 3, a. m.[2]	
3.864	1.092
3.061	1.242
2.402	1.345
1.823	1.480
1.429	1.566
1.200	1.650
1.190	1.644
Aug. 4, a. m.[2]	
4.060	1.129
3.214	1.258
2.492	1.355
1.903	1.487
1.470	1.577
1.205	1.643
1.195	1.665
Aug. 5, a. m.[2]	
4.283	1.188
4.045	1.217
3.240	1.330
2.506	1.412

M.	R.
Aug. 5, a. m.	
1.944	1.535
1.436	1.685
1.192	1.722
Aug. 6, a. m.[2]	
4.327	1.108
4.085	1.139
2.520	1.380
2.014	1.441
1.573	1.568
1.234	1.640
1.222	1.645
Aug. 8, p. m.[2]	
1.179	1.470
1.189	1.506
1.370	1.391
1.603	1.271
1.876	1.135
2.155	1.121
2.570	1.029

M.	R.
Aug. 9, a. m.[2]	
3.983	0.872
3.776	0.888
3.034	1.055
2.440	1.182
1.941	1.310
1.509	1.429
1.213	1.521
Aug. 10, a. m.[2]	
4.458	0.961
4.200	1.023
3.333	1.134
2.537	1.272
1.926	1.413
1.496	1.508
1.218	1.634
Aug. 11, a. m.[2]	
4.376	1.088
4.128	1.123
3.251	1.249
2.510	1.382

M.	R.
Aug. 11, a. m.	
1.935	1.493
1.470	1.584
1.217	1.679
Aug. 12, a. m.[2]	
4.296	1.221
4.056	1.248
3.242	1.364
2.547	1.473
1.968	1.588
1.476	1.696
1.221	1.723
Aug. 13, a. m.[2]	
4.349	1.194
4.101	1.221
3.270	1.337
2.586	1.433
1.988	1.531
1.522	1.650
1.223	1.726

M.	R.
Aug. 14, a. m.[2]	
4.336	1.191
4.090	1.227
3.227	1.337
2.558	1.441
1.998	1.526
1.521	1.646
1.235	1.723
Aug. 15, a. m.[2]	
4.390	1.161
4.138	1.182
3.293	1.286
2.576	1.402
1.984	1.505
1.532	1.633
1.232	1.707
Aug. 16, a. m.[2]	
4.125	1.270
3.247	1.396
2.593	1.444
2.005	1.532

M.	R.
Aug. 16, h. m.	
1.538	1.636
1.250	1.687
1.238	1.699
Aug. 17, a. m.[2]	
4.363	1.184
4.115	1.199
3.277	1.320
2.611	1.429
2.002	1.521
1.524	1.642
1.235	1.701
Aug. 18, a. m.[2]	
4.430	1.244
4.168	1.281
3.310	1.385
2.609	1.485
2.026	1.618
1.530	1.719
1.245	1.772

[1] To reduce readings of Pyrheliometer A. P. O. IV to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.853.

[2] Observer, L. B. A.

TABLE 17.—*Pyrheliometer readings, Mount Wilson, California, 1913*—Continued.

M.	R.
Aug. 19, a. m.[2]	
4.484	1.007
4.218	1.053
3.229	1.189
2.581	1.309
1.998	1.418
1.548	1.515
1.245	1.593
Aug. 20, a. m.[2]	
4.403	0.949
4.149	0.975
3.297	1.117
2.601	1.211
2.035	1.374
1.547	1.474
1.246	1.558
Aug. 21, a. m.[2]	
4.534	0.965
4.265	0.988
3.368	1.130
2.060	1.356
1.541	1.487
1.250	1.576
Aug. 28, a. m.[2]	
3.379	1.147
2.798	1.234
2.308	1.316
1.864	1.419
1.506	1.524
1.257	1.613
1.245	1.594
Sept. 2, a. m.[2]	
3.973	1.184
3.185	1.297
2.472	1.432
1.900	1.575
1.558	1.648
1.285	1.687
1.273	1.688
Sept. 3, a. m.[3]	
4.028	1.171
3.813	1.183
3.368	1.258
2.289	1.447
1.942	1.525
1.898	1.550
1.410	1.607
1.230	1.671
Sept. 4, a. m.[3]	
4.266	1.139
4.026	1.180
3.330	1.288
2.577	1.397
2.107	1.497
Sept. 5, a. m.[3]	
4.266	1.117
3.407	1.263
2.645	1.353
1.955	1.489
1.543	1.605
1.461	1.624
1.250	1.700
Sept. 6, a. m.[3]	
4.082	1.194
3.860	1.257
3.254	1.335
2.577	1.437
2.004	1.530
1.609	1.646
1.281	1.708
Sept. 7, a. m.[3]	
4.204	1.094
3.970	1.129
3.330	1.228
2.669	1.336
2.069	1.417
1.982	1.462
1.597	1.585
1.292	1.661
Sept. 8, a. m.[3]	
4.083	1.132
3.329	1.236
2.670	1.352
2.110	1.456
1:580	1.549
1.267	1.638
Sept. 9, a. m.[3]	
4.144	1.170
3.370	1.286
2.648	1.406
2.008	1.507
1.587	1.615
1.277	1.702
Sept. 10, a. m.[3]	
3.865	1.184
3.154	1.288
2.581	1.402
2.060	1.485
1.962	1.503
1.596	1.584
1.303	1.665
Sept 11, a. m.[3]	
4.086	1.092
3.258	1.245
2.627	1.338
2.035	1.439
1.543	1.593
1.280	1.642
Sept. 14, a. m.[3]	
4.156	1.227
3.341	1.370
2.705	1.445
2.081	1.545
1.539	1.650
1.247	1.739
Sept. 15, a. m.[3]	
4.158	1.137
3.306	1.283
2.660	1.369
2.096	1.473
2.045	1.499
1.589	1.591
1.315	1.673
Sept. 16, a. m.[3]	
4.045	1.207
3.347	1.288
2.686	1.392
2.099	1.530
2.047	1.515
1.550	1.626
1.290	1.713
Sept. 17, a. m.[3]	
4.228	1.217
3.389	1.333
2.762	1.424
2.089	1.557
1.582	1.648
1.311	1.720
Sept. 18, a. m.[3]	
4.055	1.093
3.840	1.144
3.245	1.250
2.646	1.357
2.092	1.475
1.630	1.609
1.345	1.687
Sept. 19, a. m.[3]	
4.060	1.209
3.320	1.293
2.650	1.422
2.020	1.533
1.577	1.634
1.339	1.732
Sept. 21, p. m.[3]	
1.399	1.621
1.695	1.571
2.244	1.437
2.909	1.358
3.658	1.234
4.587	1.125
Sept. 22, a. m.[3]	
4.245	1.195
3.450	1.303
2.661	1.437
2.093	1.547
1.631	1.655
1.356	1.700
Sept. 24, p. m.[3]	
1.393	1.573
1.770	1.371
2.389	1.262
3.102	1.068
3.821	0.916
Sept. 25, a. m.[3]	
4.851	1.157
4.545	1.145
3.637	1.252
2.900	1.369
2.042	1.532
1.569	1.647
1.327	1.707
Sept. 26, a. m.[3]	
4.775	1.200
3.733	1.330
2.655	1.488
2.082	1.578
1.614	1.694
1.342	1.720
Sept. 27, a. m.[3]	
4.789	1.157
3.790	1.265
2.938	1.396
2.180	1.534
1.643	1.650
Sept. 28, a. m.[3]	
5.233	1.143
4.003	1.257
3.061	1.379
2.289	1.522
1.716	1.636
1.391	1.714
Sept. 29, a. m.[3]	
4.891	1.195
3.856	1.271
3.038	1.405
2.279	1.550
1.699	1.652
1.396	1.731
Sept. 30, a. m.[3]	
4.898	1.112
3.861	1.234
3.014	1.358
2.253	1.521
Sept. 30, a. m.	
1.718	1.608
1.397	1.682
Oct. 1, a. m.[3]	
5.080	0.901
3.973	1.030
3.081	1.182
2.288	1.354
1.662	1.497
1.368	1.565
Oct. 3, a. m.[3]	
4.546	0.871
3.650	1.015
2.920	1.206
2.269	1.331
1.704	1.480
1.403	1.589
Oct. 5, a. m.[3]	
4.870	1.079
3.853	1.226
3.047	1.317
Oct. 6, a. m.[3]	
4.964	1.144
3.912	1.256
3.084	1.382
2.333	1.489
1.762	1.617
1.440	1.688
Oct. 7, a. m.[3]	
4.660	1.081
3.727	1.225
2.974	1.342
2.262	1.500
1.753	1.598
1.444	1.677
Oct. 8, a. m.[3]	
4.600	1.180
3.693	1.271
2.982	1.376
2.172	1.503
1.711	1.605
1.417	1.665
Oct. 9, a. m.[3]	
5.087	1.088
3.993	1.234
3.138	1.344
2.435	1.465
Oct. 10, a. m.[3]	
4.418	1.103
3.581	1.241
2.889	1.383
2.238	1.502
Oct. 11, a. m.[3]	
4.430	1.218
3.548	1.332
2.897	1.418
2.217	1.542
1.678	1.665
1.420	1.707
Oct. 12, a. m.[3]	
4.505	1.228
3.642	1.314
2.958	1.424
2.325	1.551
1.783	1.634
1.461	1.726
Oct. 13, a. m.[3]	
4.386	1.305
3.567	1.399
2.966	1.459
Oct. 14, a. m.[3]	
5.340	1.151
4.099	1.323
3.211	1.413
2.386	1.557
1.809	1.669
1.491	1.733
Oct. 15, a. m.[3]	
5.356	1.149
4.167	1.262
3.287	1.399
2.514	1.529
1.871	1.630
1.522	1.694
Oct. 17, a. m.[3]	
5.480	1.022
4.248	1.240
3.340	1.355
2.529	1.463
1.884	1.629
1.539	1.696
Oct. 19, a. m.[3]	
5.512	1.114
4.271	1.236
3.358	1.339
2.473	1.507
1.843	1.613
1.532	1.700
Oct. 20, a. m.[3]	
5.059	1.232
4.005	1.350
3.081	1.475
2.414	1.567
1.821	1.662
1.530	1.722
Oct. 21, a. m.[3]	
(5.860)	1.103
4.480	1.236
3.485	1.336
2.438	1.531
1.857	1.683
1.543	1.727
Oct. 22, a. m.[3]	
5.085	1.171
4.027	1.280
3.190	1.396
2.462	1.512
1.888	1.624
1.556	1.717
Oct. 23, a. m.[3]	
5.273	1.161
4.143	1.276
3.293	1.392
2.421	1.529
1.879	1.622
1.560	1.694
Oct. 24, a. m.[3]	
5.378	1.156
4.208	1.310
3.336	1.406
2.529	1.555
1.909	1.652
1.574	1.731
Oct. 25, a. m.[3]	
5.393	1.206
4.221	1.306
3.345	1.442
2.537	1.556
1.916	1.672
1.581	1.691
Oct. 26, a. m.[3]	
5.224	1.140
4.122	1.243
3.288	1.385
2.562	1.502
1.973	1.617
1.597	1.704
Oct. 27, a. m.[3]	
5.945	1.037
4.419	1.188
3.468	1.334
2.535	1.501
1.931	1.621
1.603	1.688
Oct. 28, a. m.[3]	
(5.955)	1.099
4.555	1.213
3.551	1.346

[2] Observer, L. B. A. [3] Observer, C. G. A.

TABLE 17.—*Pyrheliometer readings, Mount Wilson, California, 1913*—Continued.

M.	R.
Oct. 28, a. m.	
2.673	1.474
1.978	1.617
1.624	1.632
Oct. 31, a. m.[3]	
5.461	1.093
4.225	1.224

M.	R.
Oct. 31, a. m.	
3.366	1.335
2.603	1.474
1.993	1.558
Nov. 3, a. m.[3]	
5.687	1.226
4.424	1.340
3.495	1.452

M.	R.
Nov. 4, a. m.[3]	
5.595	1.201
4.375	1.304
3.467	1.423
2.581	1.543
1.952	1.662
1.638	1.753

M.	R.
Nov. 5, a. m.[3]	
5.603	1.145
4.380	1.280
3.475	1.364
2.589	1.524
1.959	1.630
1.660	1.692

M.	R.
Nov. 7, a. m.[3]	
6.042	1.172
4.641	1.314
3.635	1.409
2.674	1.532
2.044	1.674
1.708	1.734

M.	R.
Nov. 8, a. m.[3]	
(6.165)	1.151
4.719	1.280
3.683	1.423
2.701	1.567
2.044	1.678
1.714	1.732

M.	R.
Nov. 9, a. m.[3]	
(6.020)	1.024
4.653	1.179
3.687	1.280
2.784	1.440
2.120	1.567
1.701	1.654

[3] Observer, C. G. A.

TABLE 18.—*Pyrheliometer readings, Mount Wilson, California, 1914.*

[Pyrheliometer A. P. O. IV[1]—Observers C. G. A. and L. B. A.]

M.	R.
June 12, a. m.[2]	
3.885	1.311
3.189	1.401
2.490	1.499
1.897	1.630
1.305	1.757
1.126	1.726
1.118	1.774
June 13, a. m.[2]	
3.979	1.312
2.966	1.430
2.391	1.534
1.746	1.646
1.374	1.727
1.167	1.754
June 14, a. m.[2]	
4.025	1.309
3.213	1.386
2.504	1.495
1.746	1.627
1.379	1.702
1.169	1.748
June 15, a. m.[2]	
3.863	1.368
3.143	1.397
2.502	1.522
1.764	1.660
1.359	1.742
1.161	1.790
June 16, a. m.[2]	
4.065	1.202
3.273	1.307
2.480	1.444
1.820	1.552
1.428	1.640
1.188	1.667

M.	R.
June 19, a. m.[2]	
3.999	1.257
3.198	1.348
2.381	1.469
1.512	1.642
1.175	1.726
June 20, a. m.[2]	
4.050	1.140
3.264	1.297
2.495	1.374
1.857	1.497
1.397	1.611
1.183	1.663
June 21, a. m.[2]	
3.996	1.320
3.229	1.433
2.515	1.507
1.847	1.640
1.432	1.696
1.202	1.739
June 22, a. m.[2]	
4.220	1.252
3.373	1.336
2.417	1.506
1.807	1.612
1.406	1.697
1.168	1.741
June 23, a. m.[2]	
4.050	1.310
3.196	1.425
2.475	1.515
1.827	1.651
1.416	1.716
1.168	(1.736)

M.	R.
June 24, a. m.[2]	
4.222	1.289
3.337	1.380
2.456	1.506
1.798	1.609
1.407	1.703
1.150	1.732
June 25, a. m.[2]	
4.110	1.249
3.302	1.335
2.477	1.477
1.848	1.603
1.432	1.725
1.205	1.737
June 26, a. m.[2]	
4.060	1.355
3.270	1.469
2.420	1.590
1.809	1.678
1.397	1.763
1.164	1.826
June 30, a. m.[3]	
3.976	1.103
3.216	1.225
2.506	1.350
1.438	1.558
1.177	1.674
July 1, a. m.[2]	
4.151	1.251
3.327	1.359
2.530	1.469
1.823	1.587
1.429	1.695
1.210	1.722

M.	R.
July 2, a. m.[2]	
(4.473)	1.176
3.488	1.328
2.575	1.436
1.887	1.586
1.450	1.663
1.214	1.721
July 17, a. m.[3]	
4.207	1.228
3.355	1.347
2.561	1.463
1.909	1.550
1.244	1.690
1.094	1.718
July 18, a. m.[3]	
4.176	1.151
3.373	1.285
2.549	1.380
1.882	1.502
1.399	1.616
1.188	1.654
July 19, a. m.[3] [4]	
4.455	1.793
3.509	1.927
2.623	2.195
1.919	2.456
1.438	2.557
1.201	2.705
July 20, a. m.[3]	
4.114	1.860
3.259	2.086
2.484	2.364
1.879	2.534
1.425	2.679
1.190	2.743

M.	R.
July 21, a. m.[3]	
2.924	2.299
2.493	2.408
2.119	2.464
1.693	2.643
1.333	2.769
1.148	2.865
July 22, a. m.[3]	
4.114	2.004
3.294	2.214
2.565	2.395
1.922	2.545
1.435	2.771
1.198	2.863
July 23, a. m.[3]	
3.926	2.021
3.207	2.157
2.472	2.437
1.873	2.610
1.432	2.785
1.199	2.821
July 26, a. m.[3]	
4.184	1.844
3.298	2.246
2.523	2.384
1.835	2.576
1.395	2.740
1.170	2.809
July 27, p. m.[3]	
1.117	2.905
1.275	2.886
1.564	2.801
1.871	2.739
2.133	2.622
2.434	2.231

M.	R.
July 28, a. m.[3]	
3.304	2.437
2.780	2.546
2.265	2.677
1.749	2.817
1.362	2.953
1.164	3.018
July 29, a. m.[3]	
3.845	2.278
3.116	2.421
2.475	2.587
1.873	2.706
1.433	2.836
1.198	2.969
July 30, a. m.[3]	
2.389	2.375
2.058	2.495
1.665	2.654
1.337	2.742
1.151	2.853
Aug. 1, a. m.[3]	
3.245	1.941
2.738	2.118
2.237	2.282
1.742	2.472
1.368	2.662
1.168	2.769
Aug. 2, a. m.[3]	
3.587	2.131
2.944	2.268
2.350	2.457
1.784	2.609
1.400	2.756
1.188	2.871

M.	R.
Aug. 4, a. m.[3]	
2.926	2.251
2.510	2.376
2.114	2.495
Aug. 5, p. m.[3]	
1.168	2.679
1.381	2.593
1.730	2.321
2.096	2.196
2.482	2.017
Aug. 7, a. m.[3]	
3.321	2.029
2.783	2.189
2.235	2.327
1.741	2.506
1.361	2.671
1.163	2.795
Aug. 8, a. m.[3]	
3.237	2.283
2.730	2.353
2.229	2.508
1.739	2.646
1.369	2.746
1.169	2.867
Aug. 9, a. m.[3]	
3.374	2.320
2.799	2.427
2.209	2.616
1.736	2.749
1.364	2.837
1.168	2.978
Aug. 10, a. m.[3]	
3.485	2.192
2.901	2.345
2.320	2.538

[1] To reduce readings of Pyrheliometer A. P. O. IV to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.853.

[2] Observer, C. G. A.

[3] Observer, L. B. A.

[4] Hereafter to reduce readings of Pyrheliometer A. P. O. IV to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.511=$\frac{60}{100}$ (0.853)

TABLE 18.—*Pyrheliometer readings, Mount Wilson, California, 1914*—Continued.

M.	R.
Aug. 10, a. m.	
1.789	2.717
1.394	2.790
1.184	2.893
Aug. 11, a. m.[3]	
3.604	2.132
2.981	2.289
2.369	2.463
1.794	2.650
1.397	2.775
1.188	2.850
Aug. 12, a. m.[3]	
3.595	2.232
2.975	2.389
2.365	2.532
1.784	2.712
1.300	2.885
1.146	2.930
Aug. 13, a. m.[3]	
2.417	2.266
2.090	2.359
1.685	2.498
Aug. 14, a. m.[3]	
3.531	1.949
2.931	2.095
2.356	2.245
1.808	2.448
1.343	2.632
1.163	2.655
Aug. 16, p. m.[3]	
1.154	2.902
1.358	2.584
1.687	2.453
1.990	2.362
2.367	2.300
Aug. 17, a. m.[3]	
3.308	1.930
2.777	2.084
2.259	2.222
1.755	2.405
1.380	2.606
1.182	2.648
Aug. 18, a. m.[3]	
3.632	2.378
2.997	2.491
2.378	2.636
1.821	2.773
1.422	2.889
1.196	2.999

M.	R.
Aug. 19, a. m.[3]	
3.534	2.421
2.932	2.522
2.338	2.715
1.753	2.820
1.363	2.971
1.175	3.041
Aug. 20, a. m.[3]	
2.641	2.521
2.234	2.705
1.725	2.801
1.308	2.915
1.135	3.002
Aug. 21, a. m.[3]	
3.480	2.396
2.896	2.512
2.334	2.651
1.768	2.785
1.358	2.957
1.168	3.025
Aug. 22, a. m.[3]	
3.517	2.562
2.920	2.579
2.331	2.722
1.732	2.875
1.363	2.996
1.172	3.007
Aug. 23, a. m.[3]	
3.511	2.179
2.916	2.355
2.346	2.557
1.785	2.723
1.394	2.871
1.194	3.005
Aug. 24, a. m.[3]	
3.383	2.333
2.829	2.490
2.292	2.602
1.784	2.744
1.404	2.856
1.200	2.925
Aug. 25, a. m.[3]	
3.460	2.171
1.757	2.637
1.325	2.788
Aug. 26, a. m.[3]	
3.457	2.338
2.878	2.479
2.272	2.621
1.747	2.790

M.	R.
Aug. 26, a. m.	
1.391	2.900
1.198	2.950
Aug. 27, a. m.[3]	
2.534	2.580
2.162	2.691
1.713	2.821
1.370	2.990
1.189	3.000
Aug. 28, a. m.[3]	
3.450	2.333
2.873	2.452
2.321	2.616
1.802	2.752
1.425	2.882
1.218	2.941
Aug. 29, a. m.[3]	
3.367	2.267
2.817	2.386
2.303	2 518
1.739	2.617
1.380	2.687
1.197	2.744
Aug. 30, a. m.[3]	
3.181	1.878
2.688	2.058
2.236	2.276
1.766	2.481
1.398	2.623
1.207	2.689
Aug. 31, a. m.[3]	
3.363	2.136
2.815	2.310
2.301	2.481
1.794	2.660
1.409	2.774
1.189	2.920
Sept. 1, a. m.[3]	
3.286	2.215
2.762	2.361
2.268	2.515
1.690	2.685
1.371	2.820
Sept. 2, a. m.[3]	
3.283	2.339
2.760	2.500
2.267	2.616
1.785	2.760
1.406	2.890
1.209	2.989

M.	R.
Sept. 3, a. m.[3]	
3.321	2.340
2.786	2.516
2.301	2.631
1.795	2.795
1.427	2.851
1.225	2.968
Sept. 4, a. m.[3]	
3.320	2.310
2.786	2.387
2.285	2.548
1.806	2.670
1.428	2.803
1.233	2.890
Sept. 6, a. m.[3]	
3.282	2.353
2.760	2.501
2.268	2.667
1.789	2.776
1.438	2.864
1.228	2.931
Sept. 7, a. m.[3]	
3.321	2.518
2.787	2.629
2.287	2.742
1.800	2.864
1.433	2.981
1.237	2.985
Sept. 8, a. m.[3]	
3.359	2.382
2.815	2.498
2.305	2.635
1.801	2.800
1.440	2.840
1.240	2.941
Sept. 9, a. m.[3]	
3.360	2.352
2.814	2.497
2.306	2.648
1.830	2.798
1.452	2.891
1.247	2.948
Sept. 10, a. m.[3]	
3.362	2.273
2.817	2.435
2.325	2.536
1.853	2.713
1.449	2.822
1.249	2.921

M.	R.
Sept. 11, a. m.[3]	
3.402	2.300
2.844	2.487
2.326	2.599
1.864	2.722
1.470	2.826
1.261	2.973
Sept. 12, a. m.[3]	
3.444	2.451
2.873	2.565
2.009	2.790
1.531	2.882
1.283	2.956
Sept. 13, a. m.[3]	
3.405	2.341
2.849	2.434
2.365	2.588
1.900	2.664
1.497	2.830
1.276	2.879
Sept. 14, a. m.[3]	
3.447	2.330
2.878	2.472
2.403	2.571
1.881	2.732
1.474	2.868
1.273	2.947
Sept. 15, a. m.[3]	
3.410	2.290
2.853	2.446
2.369	2.530
1.852	2.766
1.487	2.845
1.280	2.963
Sept. 16, a. m.[3]	
3.455	2.355
2.884	2.485
2.391	2.599
1.886	2.730
1.500	2.915
1.293	2.956
Sept. 17, a. m.[3]	
3.500	2.284
2.915	2.390
Sept. 19, a. m.[3]	
3.465	2.305
2.893	2.423
2.399	2.536
1.915	2.687
1.455	2.871
1.267	2.860

M.	R.
Sept. 20, a. m.[2]	
19.31	1.037
15.82	1.210
13.89	1.321
11.43	1.500
9.97	1.591
8.82	1.726
7.91	1.801
7.16	1.907
5.52	2.116
4.67	2.239
3.74	2.408
3.56	2.427
3.11	2.526
2.53	2.679
2.044	2.804
1.615	2.924
1.383	2.963
Sept. 21, a. m.[2]	
20.36	0.956
16.62	1.130
13.89	1.279
11.86	1.404
10.31	1.539
9.10	1.650
8.12	1.720
7.33	1.786
5.76	2.007
5.34	2.073
4.32	2.256
3.46	2.441
2.97	2.536
2.47	2.670
2.022	2.774
1.606	2.916
1.348	2.990
Sept. 22, a. m.[2]	
3.651	2.320
3.083	2.515
2.505	2.596
1.969	2.756
1.597	2.838
1.349	2.948
Sept. 23, a. m.[2]	
3.704	2.220
3.528	2.272
2.910	2.402
2.414	2.542
1.919	2.676
1.582	2.841
1.359	2.892
Sept. 28, a. m.[2]	
4.482	2.056
3.558	2.210
2.855	2.427
2.195	2.600

M.	R.
Sept. 28, a. m.	
1.533	2.782
1.336	2.862
Sept. 29, a. m.[2]	
4.561	1.851
3.564	2.092
Oct. 2, a. m.[2]	
4.515	2.180
3.586	2.374
2.877	2.539
2.214	2.745
1.645	2.901
Oct. 4, a. m.[2]	
4.607	1.908
3.644	2.119
2.944	2.287
2.254	2.525
1.727	2.685
Oct. 5, a. m.[2]	
4.693	1.915
3.699	2.135
2.953	2.329
2.321	2.453
Oct. 9, a. m.[2]	
4.664	2.148
3.734	2.301
3.010	2.477
2.255	2.608
1.720	2.812
1.441	2.913
Oct. 10, a. m.[2]	
4.600	2.208
3.653	2.391
2.960	2.552
2.262	2.685
1.739	2.896
1.444	2.996
Oct. 11, a. m.[2]	
4.614	2.189
3.706	2.388
2.996	2.483
2.328	2.633
1.731	2.837
1.465	2.919
Oct. 12, a. m.[2]	
4.627	2.190
3.718	2.355
3.006	2.505
2.320	2.723
1.739	2.852
1.470	2.934

[2] Observer, C. G. A.

[3] Observer, L. B. A.

TABLE 18.—*Pyrheliometer readings, Mount Wilson, California, 1914*—Continued.

M.	R.	M.	R.	M.	R.	M.	R.	M.	R.	M.	R.	M.	R.
Oct. 13, a. m.[2]		Oct. 14, a. m.[2]		Oct. 15, a. m.[2]		Oct. 16, a. m.[2]		Oct. 18, a. m.[2]		Oct. 19, a. m.[2]		Oct. 20, a. m.[2]	
4.636	2.267	4.724	2.223	4.453	2.069	4.902	2.002	5.097	2.102	5.107	2.112	4.800	2.096
3.682	2.380	3.736	2.397	3.615	2.257	3.897	2.185	4.022	2.250	3.977	2.330	3.844	2.260
3.012	2.536	3.020	2.549	2.973	2.467	3.125	2.377	3.174	2.453	3.062	2.486	3.101	2.422
2.326	2.726	2.364	2.702	2.356	2.589	2.444	2.394	2.426	2.688	2.400	2.660	2.441	2.602
1.744	2.902	1.764	2.860	1.763	2.802			1.777	2.843	1.783	2.850	1.825	2.792
1.480	2.997	1.480	2.970	1.489	2.892			1.495	2.869	1.516	2.925	1.543	2.887

[2] Observer, C. G. A.

TABLE 19.—*Pyrheliometer readings, Mount Wilson, California, 1915.*

[Pyrheliometer A. P. O. IV[1]—Observers C. G. A. and L. B. A.]

M.	R.
June 8, a. m.[2]	
4.324	1.923
3.435	2.145
2.777	2.308
2.301	2.401
1.841	2.536
1.407	2.722
1.209	2.814
June 10, a. m.[2]	
4.297	2.222
3.459	2.378
2.792	2.518
2.329	2.629
1.828	2.795
1.415	2.883
1.172	2.993
June 11, a. m.[2]	
4.166	2.309
3.617	2.352
3.067	2.492
2.577	2.581
2.151	2.706
1.759	2.827
1.410	2.906
1.196	3.033
June 12, a. m.[3]	
4.044	2.268
3.294	2.431
2.662	2.540
1.990	2.720
1.450	2.848
1.201	2.912
June 13, a. m.[3]	
4.323	2.246
3.476	2.420
2.681	2.621
2.051	2.782
1.515	2.875
1.240	2.941

M.	R.
June 16, a. m.[2]	
4.122	2.184
3.310	2.297
2.562	2.482
2.034	2.609
June 18, a. m.[2]	
4.287	2.216
3.455	2.363
2.623	2.547
2.071	2.719
June 19, a. m.[2]	
3.575	2.417
2.841	2.542
2.517	2.582
1.934	2.757
1.537	2.846
June 22, a. m.[2]	
4.220	2.316
3.373	2.444
2.599	2.585
2.057	2.718
1.584	2.829
1.295	2.935
June 24, a. m.[2]	
4.164	1.943
3.265	2.175
2.557	2.366
2.031	2.580
1.518	2.784
1.196	2.878
June 25, a. m.[2,3]	
4.110	2.034
3.232	2.257
2.558	2.441
2.019	2.674
1.536	2.856
1.250	2.941

M.	R.
June 26, a. m.[2,3]	
4.115	2.153
3.270	2.337
2.560	2.503
2.020	2.640
1.557	2.826
1.260	2.896
June 27, a. m.[2]	
4.117	1.960
3.307	2.114
2.582	2.310
2.046	2.481
1.592	2.653
1.253	2.796
June 28, a. m.[2]	
(4.363)	2.088
3.349	2.281
2.606	2.474
2.060	2.652
1.579	2.839
1.253	2.944
July 3, a. m.[2,4]	
(4.60)	1.951
3.580	2.147
2.797	2.334
2.145	2.499
1.547	2.679
1.220	2.770
July 4, a. m.[2]	
3.145	2.362
2.567	2.502
2.134	2.601
1.548	2.800
1.255	2.916
July 5, a. m.[2]	
4.366	2.175
3.397	2.362

M.	R.
July 5. a. m.	
2.638	2.514
2.055	2.712
1.517	2.845
1.243	2.930
July 6, a. m.[2]	
4.033	2.179
3.226	2.375
2.556	2.503
2.006	2.677
1.564	2.821
1.260	2.911
July 7, a. m.[2]	
4.333	2.020
3.415	2.198
2.604	2.361
2.009	2.556
1.579	2.688
1.258	2.802
July 8, a. m.[2]	
4.231	2.057
3.352	2.243
2.587	2.398
2.050	2.533
1.602	2.698
1.269	2.803
July 9, a. m.[3]	
(4.43)	2.037
3.437	2.222
2.660	2.396
2.108	2.576
1.604	2.729
1.255	2.847
July 10, a. m.[2]	
4.328	2.116
3.449	2.268
2.644	2.438

M.	R.
July 10, a. m.	
2.057	2.580
1.563	2.730
1.267	2.809
July 11, a. m.[2]	
4.411	2.138
3.502	2.309
2.698	2.494
2.075	2.644
1.600	2.773
1.268	2.896
July 12, a. m.[2]	
4.252	2.174
3.437	2.340
2.706	2.476
2.120	2.617
1.610	2.778
1.275	2.891
July 13, a. m.[2]	
4.273	2.080
3.451	2.218
2.689	2.414
2.096	2.611
July 14, a. m.[2]	
4.359	2.188
3.466	2.355
2.675	2.520
2.101	2.675
1.614	2.832
1.260	2.968
July 15, a. m.[2]	
4.262	2.212
3.480	2.370
2.684	2.575
2.135	2.717
1.632	2.901
1.268	3.036

M.	R.
July 16, a. m.[2]	
4.539	2.223
3.495	2.418
2.692	2.610
2.126	2.749
1.604	2.915
1.270	3.019
July 17, a. m.[2,3]	
4.501	2.205
3.555	2.437
2.750	2.620
2.160	2.803
1.571	2.950
1.274	3.007
July 18, a. m.[2]	
4.402	2.204
3.532	2.336
2.737	2.516
2.122	2.708
1.602	2.826
1.279	2.902
July 26, a. m.[2]	
4.477	2.167
3.532	2.355
2.757	2.546
2.090	2.677
1.614	2.818
1.305	2.918
July 27, a. m.[2]	
4.518	2.230
3.513	2.421
2.770	2.571
2.140	2.745
1.648	2.882
1.250	3.011
1.169	3.009

M.	R.
July 28, a. m.[2,3]	
4.492	2.243
3.540	2.414
2.812	2.580
2.147	2.754
1.661	2.872
1.302	2.997
July 29, a. m.[3]	
4.601	2.112
3.650	2.280
2.852	2.461
2.185	2.637
1.604	2.807
1.251	2.923
July 30, a. m.[3]	
4.442	2.102
3.548	2.273
2.763	2.461
2.134	2.625
1.580	2.774
1.269	2.885
July 31, a. m.[3]	
4.292	2.170
3.450	2.322
2.728	2.473
2.143	2.624
1.577	2.787
1.268	2.893
Aug. 1, a. m.[3]	
4.268	2.063
3.434	2.256
2.768	2.415
2.136	2.609
1.574	2.780
1.257	2.855

[1] To reduce readings of Pyrheliometer A. P. O. IV to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.511.

[2] Observer, C. G. A.

[3] Observer, L. B. A.

[4] Hereafter we employ air masses corrected according to Bemporad.

TABLE 19.—*Pyrheliometer readings, Mount Wilson, California, 1915*—Continued.

M.	R.
Aug. 2, a. m.[3]	
4.247	2.109
3.421	2.278
2.374	2.438
2.061	2.626
1.537	2.755
1.262	2.892
Aug. 3, a. m.[3]	
4.350	2.167
3.487	2.335
2.751	2.467
2.125	2.717
1.569	2.812
1.269	2.980
Aug. 6, a. m.[3]	
4.295	2.181
3.449	2.373
2.750	2.507
2.082	2.661
1.541	2.856
1.259	2.912
Aug. 7, a. m.[3]	
4.402	2.192
3.516	2.398
2.791	2.521
2.134	2.732
1.573	2.861
1.273	2.989
Aug. 8, a. m.[3]	
4.452	2.211
3.548	2.394
2.811	2.531
2.173	2.732
1.606	2.922
Aug. 9, a. m.[3]	
4.434	2.226
3.535	2.376
2.803	2.553
2.154	2.724
1.590	2.895
1.285	2.987
Aug. 10, a. m.[3]	
4.419	2.285
3.525	2.462
2.833	2.578
2.179	2.734
1.631	2.937
1.302	3.012
Aug. 11, a. m.[3]	
4.403	1.977
3.515	2.158

M.	R.
Aug. 11, a. m.	
2.788	2.330
2.175	2.528
1.594	2.759
1.277	2.908
Aug. 12, a. m.[3]	
4.456	2.242
3.548	2.419
2.836	2.589
2.187	2.755
1.599	2.913
1.290	3.013
Aug. 13, a. m.[3]	
4.511	2.221
3.581	2.381
2.856	2.551
2.215	2.746
1.597	2.939
1.291	3.007
Aug. 14, a. m.[3]	
4.429	2.159
3.528	2.327
2.823	2.503
2.195	2.668
1.624	2.889
1.308	2.969
Aug. 15, a. m.[3]	
4.485	2.219
3.563	2.382
2.844	2.509
2.192	2.715
1.623	2.888
1.308	3.004
Aug. 16, a. m.[3]	
4.471	2.291
3.554	2.431
2.838	2.553
2.220	2.739
1.652	2.911
1.316	3.019
Aug. 17, a. m.[2]	
(4.674)	2.238
3.726	2.406
2.946	2.592
2.216	2.752
1.682	2.882
1.319	2.981
Aug. 18, a. m.[2]	
4.447	2.264
3.581	2.409
2.829	2.565
2.152	2.724

M.	R.
Aug. 18, a. m.	
1.664	2.871
1.304	2.977
Aug. 19, a. m.[2]	
4.373	2.256
3.490	2.413
2.720	2.580
2.136	2.760
1.625	2.853
1.287	2.996
Aug. 20, a. m.[2]	
4.297	2.032
3.326	2.204
*2.577	2.403
2.064	2.586
1.618	2.639
1.270	2.757
Aug. 21, a. m.[2]	
4.354	2.071
3.436	2.264
2.737	2.395
2.145	2.523
1.639	2.761
1.285	2.835
Aug. 22, a. m.[2]	
4.346	2.264
3.431	2.437
2.685	2.593
2.129	2.710
1.595	2.910
1.272	2.982
Aug. 23, a. m.[2]	
4.340	2.039
3.466	2.214
2.731	2.398
2.142	2.565
1.661	2.776
1.303	2.883
Aug. 24, a. m.[2]	
4.334	2.198
3.463	2.378
2.729	2.553
2.155	2.716
1.616	2.870
1.286	2.946
Aug. 25, a. m.[2]	
4.262	2.397
3.417	2.552
2.677	2.703
2.111	2.825
1.659	2.962
1.304	3.061

M.	R.
Aug. 27, a. m.[2]	
4.447	1.776
3.534	2.002
2.771	2.169
2.180	2.286
1.645	2.499
1.313	2.618
Aug. 28, a. m.[2]	
4.810	1.743
3.804	1.961
2.877	2.172
2.150	2.366
1.582	2.618
1.281	2.689
Aug. 29, a. m.[2]	
(4.968)	1.728
3.851	1.951
2.932	2.168
2.225	2.400
1.556	2.592
1.329	2.696
Aug. 31, a. m.[2]	
4.362	1.782
3.439	1.958
2.739	2.130
2.093	2.333
1.639	2.516
1.322	2.626
Sept. 3, a. m.[2]	
4.295	1.759
3.518	1.919
2.789	2.128
2.148	2.375
1.648	2.552
1.312	2.702
Sept. 4, a. m.[2]	
4.356	1.980
3.516	2.160
2.814	2.321
2.164	2.492
1.656	2.696
1.339	2.840
Sept. 5, a. m.[2]	
4.353	1.926
3.474	2.132
2.788	2.299
2.136	2.503
1.673	2.645
1.351	2.768
Sept. 6, a. m.[2, 3]	
4.351	1.912
3.557	2.102

M.	R.
Sept. 6, a. m.	
2.815	2.321
2.209	2.517
1.690	2.674
1.346	2.851
Sept. 7, a. m.[2]	
4.355	2.093
3.476	2.264
2.763	2.458
2.181	2.583
1.612	2.876
1.327	2.950
Sept. 8, a. m.[2]	
4.353	2.336
3.515	2.428
2.789	2.609
2.197	2.750
1.635	2.907
1.325	3.007
Sept. 12, a. m.[2]	
4.362	2.308
3.480	2.491
2.769	2.634
2.144	2.824
1.662	2.946
1.344	2.997
Sept. 15, a. m.[2]	
4.306	2.042
3.530	2.208
2.802	2.367
2.151	2.595
1.684	2.769
1.347	2.838
Sept. 16, a. m.[2]	
4.372	1.886
3.410	2.083
2.729	2.283
2.153	2.528
1.645	2.703
1.347	2.819
Sept. 17, a.m.[2]	
4.443	2.046
3.452	2.205
2.757	2.396
2.101	2.638
1.654	2.776
1.367	2.893
Sept. 18, a. m.[2]	
4.658	2.026
3.625	2.247
2.863	2.507

M.	R.
Sept. 18, a. m.	
2.188	2.708
1.650	2.858
1.378	2.997
Sept. 19, a. m.[2]	
4.199	2.297
3.421	2.451
2.714	2.600
2.149	2.765
1.660	2.898
1.392	2.974
Sept. 20, a. m.[2, 3]	
4.672	2.031
4.031	2.172
3.349	2.308
2.694	2.475
2.084	2.639
1.610	2.805
1.377	2.884
Sept. 22, a. m.[2]	
5.184	2.056
4.043	2.250
3.115	2.451
2.232	2.659
1.618	2.863
1.379	2.930
Sept. 23, a. m.[2]	
5.385	2.088
4.160	2.303
3.088	2.550
2.190	2.826
1.674	2.954
1.371	3.040
Sept. 27, a. m.[2]	
4.803	2.168
3.815	2.380
2.988	2.544
2.267	2.713
1.655	2.914
1.391	2.985
Sept. 28, a. m.[2]	
5.434	2.130
4.137	2.346
3.145	2.549
2.257	2.748
1.700	2.906
1.408	3.011
Sept. 29, a. m.[2]	
5.246	1.906
4.034	2.105

M.	R.
Sept. 29, a. m.	
3.087	2.346
2.292	2.596
1.705	2.778
1.406	2.887
Sept. 30, a. m.[2]	
5.366	1.950
4.102	2.176
3.160	2.386
2.347	2.600
1.733	2.796
1.443	2.946
Oct. 1, a. m.[2]	
5.085	1.977
3.994	2.214
3.131	2.418
2.270	2.617
1.714	2.846
1.434	2.920
Oct. 2, a. m.[2]	
5.185	2.219
4.055	2.395
3.169	2.556
2.307	2.808
1.704	2.918
1.430	2.967
Oct. 3, a. m.[2]	
5.293	1.965
4.067	2.195
3.178	2.386
2.314	2.627
1.738	2.795
1.432	2.895
Oct. 4, a. m.[2]	
4.309	2.180
3.285	2.451
2.350	2.664
1.743	2.885
1.455	2.974
Oct. 5, a. m.[2]	
5.830	2.105
4.444	2.321
3.327	2.560
2.176	2.850
1.597	2.970
Oct. 6, a. m.[2]	
5.845	2.186
4.453	2.413
3.371	2.612
2.377	2.812

[2] Observer, C. G. A. [3] Observer, L. B. A.

TABLE 19.—*Pyrheliometer readings, Mount Wilson, California, 1915*—Continued.

M.	R.
Oct. 6, a. m.	
1.783	2.967
1.462	3.065
Oct. 7, a. m.[2]	
5.976	2.146
4.531	2.342
3.380	2.570
2.401	2.805
1.456	2.998
1.407	3.065
Oct. 8, a. m.[2]	
5.761	2.025
4.408	2.241
3.387	2.476
2.406	2.725
1.793	2.971

M.	R.
Oct. 8, a. m.	
1.500	3.046
1.484	3.044
Oct. 9, a. m.[2]	
5.892	2.117
4.485	2.341
3.395	2.529
2.448	2.747
1.454	3.050
Oct. 11, a. m.[2]	
6.435	1.984
4.719	2.250
3.610	2.485
2.444	2.751
1.788	2.831
1.502	2.938

M.	R.
Oct. 12, a. m.[2]	
6.057	1.900
4.585	2.151
3.536	2.360
2.450	2.612
1.794	2.822
1.506	2.936
Oct. 13, a. m.[2]	
5.624	2.006
4.337	2.217
3.430	2.387
2.423	2.642
1.779	2.802
1.488	2.901
Oct. 14, a. m.[2]	
5.538	1.999
4.290	2.188

M.	R.
Oct. 14, a. m.	
3.048	2.480
2.276	2.685
1.757	2.815
1.482	2.911
Oct. 15, a. m.[2]	
4.768	2.053
3.825	2.229
3.084	2.234
2.312	2.637
1.738	2.790
1.488	2.844
Oct. 16, a. m.[2]	
5.882	2.007
4.497	2.213
3.419	2.471

M.	R.
Oct. 16, a. m.	
2.379	2.732
1.790	2.892
1.532	2.957
Oct. 17, a. m.[2]	
6.526	1.941
4.865	2.180
3.428	2.454
2.435	2.688
1.848	2.874
1.562	2.971
Oct. 18, a. m.[2]	
6.026	2.017
4.585	2.260
3.474	2.466
2.547	2.691

M.	R.
Oct. 18, a. m.	
1.913	2.875
1.593	2.974
Oct. 19, a. m.[2]	
6.697	2.069
4.965	2.302
3.642	2.552
2.535	2.785
1.878	2.995
1.555	3.047
Oct. 20, a. m.[2]	
6.430	2.133
4.825	2.315
3.654	2.552
2.581	2.754

M.	R.
Oct. 20, a. m.	
1.910	2.915
1.591	3.001
Oct. 21, a. m.[2]	
7.038	1.990
5.156	2.256
3.703	2.505
2.648	2.746
1.950	2.930
1.610	3.037
Oct. 22, a. m.[2]	
6.605	2.121
4.925	2.320
3.758	2.543
2.616	2.770
2.084	2.912

[2] Observer, C. G. A.

TABLE 20.—*Pyrheliometer readings, Mount Wilson, California, 1916.*

[Pyrheliometer A. P. O. IV[1]—Observers C. G. A. and L. B. A.

M.	R.
June 16, a. m.[2]	
3.854	2.250
3.021	2.406
2.488	2.511
1.966	2.679
1.469	2.787
1.229	2.896
June 17, a. m.[2]	
3.849	2.076
3.173	2.196
2.447	2.404
1.943	2.540
1.475	2.690
1.224	2.821
June 19, a. m.[2]	
3.894	2.058
3.203	2.251
2.523	2.435
1.988	2.597
1.568	2.745
1.273	2.845
June 20, a. m.[2]	
3.844	2.247
3.169	2.350
2.543	2.495
1.843	2.713
1.498	2.780

M.	R.
June 22, a. m.[2]	
3.992	2.145
3.236	2.328
2.522	2.503
1.987	2.667
1.425	2.824
1.177	2.944
June 23, a. m.[2]	
3.845	2.144
3.107	2.275
2.483	2.452
1.929	2.651
1.547	2.784
1.225	2.938
June 24, a. m.[2]	
3.998	2.118
3.238	2.315
2.545	2.485
1.988	2.620
1.548	2.801
1.258	2.880
June 25, a. m.[2]	
3.948	2.154
3.205	2.237
2.960	2.309
2.505	2.416
1.977	2.582

M.	R.
June 25, a. m.	
1.569	2.733
1.280	2.821
June 26, a. m.[2]	
3.953	2.166
3.243	2.299
2.526	2.463
2.002	2.618
1.576	2.805
1.255	2.883
1.229	2.882
June 27, a. m.[2]	
4.061	2.125
3.179	2.312
2.528	2.451
2.003	2.616
1.131	2.923
June 30, a. m.[2]	
3.979	2.175
3.224	2.331
2.515	2.473
1.983	2.634
1.572	2.747
1.271	2.856
July 1, a. m.[2]	
3.936	2.209
3.196	2.335

M.	R.
July 1, a. m.	
2.498	2.518
1.973	2.663
1.546	2.790
1.224	2.895
July 2, a. m.[2]	
3.998	2.215
3.238	2.360
2.564	2.523
2.012	2.637
1.581	2.754
1.279	2.869
1.265	2.904
July 3, a. m.[2]	
4.060	2.271
3.314	2.417
2.567	2.592
2.064	2.719
1.582	2.862
1.261	2.943
July 4, a. m.[2]	
4.070	2.282
3.250	2.443
2.571	2.600
2.003	2.756
1.597	2.877
1.276	2.980

M.	R.
July 5, a. m.[2]	
4.084	2.312
3.190	2.455
2.555	2.653
2.031	2.745
1.537	2.924
1.270	2.990
July 6, a. m.[2]	
4.154	2.226
3.337	2.407
2.581	2.571
1.996	2.723
1.532	2.850
1.264	2.921
July 7, a. m.[2]	
4.228	2.295
3.348	2.482
2.608	2.678
2.037	2.811
1.595	2.946
1.258	3.021
1.244	3.043
July 8, a. m.[2]	
3.924	2.405
3.288	2.557
2.614	2.718
1.990	2.840
1.561	2.997
1.232	3.062

M.	R.
July 9, a. m.[2]	
4.264	2.308
3.372	2.471
2.642	2.636
2.057	2.840
1.584	2.925
1.266	3.050
July 10, a. m.[2]	
3.852	2.186
3.238	2.266
2.542	2.388
1.996	2.525
1.572	2.664
1.257	2.786
July 11, a. m.[2]	
4.129	1.944
3.320	2.097
2.591	2.266
2.026	2.482
1.581	2.607
1.264	2.713
July 12, a. m.[2]	
4.149	1.958
3.371	2.138
2.664	2.340
2.068	2.484
1.626	2.634
1.248	2.745

M.	R.
July 15, a. m.[2]	
4.219	2.129
3.340	2.295
2.644	2.470
2.082	2.650
1.555	2.749
1.263	2.815
July 16, a. m.[2]	
4.129	2.031
3.318	2.148
2.653	2.365
2.047	2.565
1.613	2.766
1.267	2.915
July 17, a. m.[2]	
4.215	2.250
3.371	2.411
2.617	2.596
2.052	2.743
1.602	2.837
1.202	3.013
July 18, a. m.[2]	
4.125	2.311
3.313	2.455
2.540	2.625
1.994	2.770
1.569	2.884
1.227	2.945

[1] To reduce readings of Pyrheliometer A. P. O. IV to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.511.
[2] Observer, C. G. A.

TABLE 20.—*Pyrheliometer readings, Mount Wilson, California, 1916*—Continued.

M.	R.
July 19, a. m.[2]	
4.152	2.080
3.405	2.247
2.660	2.415
2.038	2.601
1.600	2.720
1.289	2.839
July 22, a. m.[2]	
4.627	1.689
3.672	1.893
2.842	2.081
1.921	2.381
1.429	2.559
1.191	2.704
July 23, a. m.[2]	
4.330	1.655
3.405	1.887
2.728	2.100
1.972	2.354
1.550	2.507
1.217	2.683
July 24, a. m.[2]	
4.244	1.856
3.424	2.037
2.579	2.242
1.955	2.498
1.547	2.631
1.259	2.787
July 25, a. m.[2]	
4.404	2.187
3.447	2.379
2.754	2.505
2.035	2.709
1.585	2.821
1.265	2.956
July 28, a. m.[3]	
4.592	2.267
3.690	2.413
2.932	2.533
2.168	2.753
1.624	2.892
1.270	2.983
July 29, a. m.[3]	
4.709	2.224
3.763	2.354
2.978	2.525
2.238	2.700
1.668	2.832
1.260	2.970
July 30, a. m.[2]	
4.542	2.045
3.611	2.270
2.801	2.436

M.	R.
July 30. a. m.	
2.112	2.612
1.648	2.753
1.305	2.843
July 31, a. m.[2]	
4.512	1.996
3.592	2.163
2.764	2.347
2.163	2.510
1.653	2.653
1.243	2.827
Aug. 10, a. m.[3]	
4.528	1.524
3.594	1.758
2.893	1.982
2.268	2.213
1.500	2.585
1.263	2.737
Aug. 11, a. m.[3]	
4.733	1.663
3.765	1.956
2.973	2.102
2.232	2.314
1.626	2.578
1.255	2.790
Aug. 12, a. m.[3]	
4.716	2.051
3.757	2.199
2.798	2.430
2.165	2.559
1.617	2.747
1.283	2.871
Aug. 13, a. m.[3]	
4.626	2.093
3.697	2.284
2.959	2.391
2.272	2.587
1.668	2.825
1.267	2.964
Aug. 14, a. m.[3]	
4.340	2.098
3.511	2.269
2.812	2.394
2.174	2.583
1.614	2.834
1.275	2.938
Aug. 15, a. m.[3]	
4.830	1.972
3.823	2.147
2.918	2.340
2.217	2.594
1.644	2.766
1.289	2.909

M.	R.
Aug. 16, a. m.[3]	
4.590	2.060
3.195	2.341
2.520	2.521
1.991	2.658
1.570	2.801
1.260	2.936
Aug. 17, a. m.[2]	
4.803	2.065
3.619	2.246
2.797	2.475
2.120	2.635
1.655	2.800
1.287	2.900
Aug. 18, a. m.[2]	
4.566	2.064
3.567	2.269
2.716	2.478
2.077	2.653
1.632	2.770
1.300	2.856
Aug. 19, a. m.[2]	
4.557	2.094
3.475	2.304
2.663	2.483
2.062	2.661
1.617	2.812
1.257	2.909
Aug. 20, a. m.[2]	
5.382	2.032
4.099	2.252
3.070	2.490
2.202	2.714
1.608	2.933
1.231	2.988
Aug. 21, a. m.[3]	
4.682	1.914
3.727	2.102
2.917	2.298
2.084	2.570
1.553	2.744
1.217	2.911
Aug. 22, a. m.[2]	
4.390	2.035
3.498	2.172
2.725	2.417
2.096	2.617
1.600	2.745
1.232	2.894
Aug. 25, a. m.[2]	
4.506	1.735
3.706	1.915
2.820	2.084

M.	R.
Aug. 25, a. m.	
2.226	2.242
1.715	2.495
1.333	2.670
Aug. 27, a. m.[2]	
4.714	1.776
3.608	1.982
2.763	2.228
2.146	2.385
1.666	2.568
1.316	2.675
Aug. 28, a. m.[2]	
3.518	2.043
2.787	2.259
2.176	2.433
1.666	2.647
1.317	2.740
Aug. 29, a. m.[2]	
4.782	2.078
3.646	2.280
2.811	2.472
2.089	2.630
1.629	2.788
1.276	2.880
Aug. 30, a. m.[2]	
4.853	1.974
3.688	2.180
2.810	2.399
2.130	2.589
1.667	2.726
1.306	2.890
Aug. 31, a. m.[2]	
4.698	2.151
3.596	2.387
2.783	2.544
2.131	2.753
1.453	2.960
1.288	3.036
Sept. 1, a. m.[2]	
4.694	2.185
3.640	2.396
2.809	2.561
2.117	2.726
1.646	2.837
1.278	2.994
Sept. 2, a. m.[2]	
4.618	2.084
3.640	2.270
2.808	2.470
2.145	2.641
1.677	2.810
1.295	2.926

M.	R.
Sept. 3, a. m.[2]	
4.771	1.747
3.638	2.046
2.782	2.290
2.103	2.507
1.670	2.645
1.306	2.823
Sept. 4, a. m.[2]	
4.847	1.942
3.729	2.153
2.807	2.404
2.175	2.604
1.719	2.804
1.286	2.848
1.274	2.929
Sept. 5, a. m.[2]	
4.688	1.996
3.683	2.157
2.835	2.407
2.222	2.613
1.720	2.745
1.317	2.885
Sept. 6, a. m.[2]	
4.615	2.031
3.548	2.276
2.707	2.479
2.078	2.700
1.609	2.809
1.290	2.936
Sept. 7, a. m.[2]	
4.615	2.143
3.638	2.311
2.837	2.527
2.093	2.725
1.633	2.899
1.302	2.988
Sept. 8, a. m.[2]	
4.541	2.005
3.637	2.181
2.836	2.363
2.179	2.553
1.640	2.738
1.262	2.915
Sept. 9, a. m.[2]	
4.543	2.265
3.595	2.432
2.838	2.592
2.211	2.747
1.664	2.865
1.309	2.953
Sept. 10, a. m.[2]	
4.411	2.144
3.510	2.317

M.	R.
Sept. 10, a. m.	
2.812	2.438
2.139	2.665
1.645	2.837
1.297	2.945
Sept. 11, a. m.[2]	
4.618	1.959
3.640	2.175
2.841	2.346
2.169	2.597
1.682	2.750
1.321	2.921
Sept. 12, a. m.[2]	
4.621	2.130
3.645	2.320
2.842	2.491
2.101	2.710
1.677	2.819
1.318	2.954
Sept. 13, a. m.[3]	
4.854	2.167
3.835	2.381
3.046	2.520
2.348	2.680
1.734	2.849
1.343	2.997
Sept. 14, a. m.[3]	
4.858	2.025
3.838	2.218
3.018	2.444
2.283	2.572
1.713	2.762
1.336	2.889
Sept. 15, a. m.[3]	
4.865	1.832
3.842	2.025
3.052	2.256
2.371	2.484
1.708	2.697
1.336	2.826
Sept. 16, a. m.[3]	
4.949	1.716
3.895	1.937
3.055	2.174
2.338	2.361
1.695	2.595
1.332	2.758
Sept. 17, a. m.[3]	
4.795	1.829
3.801	2.023
2.997	2.243
2.309	2.459
1.721	2.641
1.345	2.767

M.	R.
Sept. 18, a. m.[3]	
4.800	1.645
3.756	1.870
3.001	2.099
2.329	2.333
1.756	2.575
1.365	2.743
Sept. 23, a. m.[3]	
4.916	1.909
3.880	2.130
3.052	2.325
2.348	2.481
1.712	2.743
1.353	2.820
Sept. 27, a. m.[3]	
4.868	2.083
3.854	2.240
3.073	2.408
2.330	2.623
1.684	2.812
1.355	2.907
Sept. 28, a. m.[3]	
4.877	2.116
3.863	2.284
3.049	2.481
2.351	2.630
1.732	2.827
1.372	2.913
Oct. 5, a. m.[3]	
4.955	1.983
3.820	2.183
3.063	2.372
2.277	2.570
1.722	2.709
Oct. 8, a. m.[3]	
4.827	2.064
3.848	2.169
3.116	2.301
2.238	2.540
1.738	2.653
1.395	2.828
Oct. 12, a. m.[3]	
4.872	1.749
3.885	1.945
3.116	2.119
2.248	2.437
1.749	2.590
Oct. 14, a. m.[3]	
5.062	1.867
4.006	2.072
3.196	2.281
2.517	2.477
1.848	2.682
1.453	2.848

[2] Observer, C. G. A. [3] Observer, L. B. A.

TABLE 20.—*Pyrheliometer readings, Mount Wilson, California, 1916*—Continued.

M.	R.	M.	R.	M.	R.	M.	R.	M.	R.	M.	R.	M.	R.
Oct. 15, a. m.[3]		Oct. 16, a. m.[3]		Oct. 17, a. m.[3]		Oct. 18, a. m.[3]		Oct. 19, a. m.[3]		Oct. 20, a. m.[3]		Oct. 22, a. m.[3]	
4.985	2.005	5.001	2.003	5.014	2.034	4.943	2.248	4.957	2.252	4.890	2.296	4.918	2.180
3.962	2.241	3.977	2.200	3.984	2.231	3.894	2.454	3.955	2.441	3.916	2.498	3.939	2.410
3.170	2.393	3.182	2.353	3.191	2.390	3.049	2.611	3.088	2.630	3.155	2.643	3.174	2.550
2.454	2.590	2.481	2.519	2.454	2.544	2.427	2.766	2.484	2.756	2.510	2.787	2.543	2.699
1.854	2.750	1.869	2.777	1.852	2.781	1.843	2.908	1.881	2.967	1.913	2.984	1.961	2.904
1.478	2.880	1.485	2.872	1.480	2.907	1.473	3.033	1.511	3.040	1.531	3.068		

[3] Observer, L. B. A.

TABLE 21.—*Pyrheliometer readings, Mount Wilson, California, 1917.*

[Pyrheliometer A. P. O. IV[1]—Observer L. B. A.]

M.	R.
July 1, a. m.	
4.200	1.598
3.409	1.750
2.715	2.007
2.022	2.292
1.443	2.521
1.200	2.696
July 2, a. m.	
4.157	1.335
3.379	1.598
2.744	1.790
2.076	2.014
1.580	2.286
1.159	2.554
July 3, a. m.	
3.902	1.586
3.208	1.781
2.632	1.960
2.077	2.148
1.567	2.409
1.180	2.616
July 4, a. m.	
3.912	1.780
3.248	1.936
2.681	2.118
2.136	2.310
1.611	2.480
1.183	2.719
July 5, a. m.	
4.194	1.974
3.440	2.160
2.784	2.305
2.197	2.511
1.620	2.695
1.188	2.838
July 6, a. m.	
(4.580)	1.890
3.697	2.060

M.	R.
July 6, a. m.	
2.951	2.300
2.279	2.491
1.683	2.696
1.212	2.870
July 7, a. m.	
(4.530)	1.851
3.666	2.066
2.929	2.231
2.236	2.453
1.652	2.677
1.216	2.847
July 8, a. m.	
(4.482)	2.249
3.635	2.411
2.910	2.561
2.272	2.697
1.679	2.893
1.211	3.022
July 9, a. m.	
(4.506)	2.246
3.648	2.420
2.918	2.547
2.276	2.675
1.698	2.823
July 18, a. m.	
3.139	1.996
2.624	2.109
2.098	2.323
1.429	2.565
1.117	2.695
July 19, a. m.	
4.512	1.871
3.644	2.073
2.938	2.298
2.252	2.451
1.644	2.653
1.210	2.798

M.	R.
July 29, a. m.	
4.851	1.808
3.853	2.007
3.064	2.161
2.285	2.326
1.644	2.596
1.306	2.727
Aug. 1, a. m.	
4.847	1.698
3.847	1.910
3.060	2.092
2.351	2.328
1.705	2.522
1.290	2.723
Aug. 2, a. m.	
4.820	1.686
3.284	2.022
2.679	2.191
2.180	2.370
1.646	2.564
1.259	2.714
Aug. 5, a. m.	
4.751	1.683
3.783	1.894
3.018	2.105
2.342	2.296
1.720	2.509
1.275	2.684
Aug. 6, a. m.	
4.809	1.803
3.818	1.977
3.039	2.182
2.303	2.375
1.700	2.592
1.281	2.744
Aug. 7, p. m.	
1.220	2.813
1.529	2.707

M.	R.
Aug. 7, p. m.	
1.865	2.593
2.263	2.454
Aug. 8, a. m.	
4.844	2.019
3.840	2.192
3.052	2.346
2.361	2.489
1.711	2.701
1.259	2.821
Aug. 12, a. m.	
4.700	1.631
3.745	1.906
2.991	2.076
2.324	2.338
1.639	2.532
1.295	2.673
Aug. 13, a. m.	
4.684	1.531
3.733	1.741
2.953	1.980
2.286	2.262
1.683	2.434
Aug. 14, a. m.	
4.672	1.310
3.725	1.520
2.977	1.720
2.299	1.977
1.681	2.245
1.252	2.491
Aug. 16, a. m.	
(4.796)	1.682
3.801	1.922
3.024	2.110
2.325	2.360
1.703	2.599
1.275	2.776

M.	R.
Aug. 17, a. m.	
4.782	2.162
3.793	2.363
3.018	2.508
2.323	2.723
1.702	2.903
1.285	2.981
Aug. 18, a. m.	
4.696	2.056
3.738	2.231
2.984	2.390
2.303	2.631
1.692	2.833
1.285	2.939
Aug. 19, a. m.	
4.841	2.003
3.828	2.198
3.039	2.413
2.334	2.550
1.707	2.762
1.292	2.859
Aug. 20, a. m.	
4.750	1.829
3.773	2.049
3.004	2.271
2.315	2.425
1.707	2.700
1.304	2.823
Aug. 21, a. m.	
4.818	2.136
3.811	2.288
3.029	2.474
2.329	2.663
1.698	2.802
1.276	2.985
Aug. 22, a. m.	
4.735	2.033
3.759	2.241

M.	R.
Aug. 22, a. m.	
2.996	2.409
2.327	2.588
1.705	2.783
1.301	2.939
Aug. 26, a. m.	
(4.860)	2.052
3.836	2.205
3.042	2.394
2.337	2.576
1.729	2.729
1.318	2.874
Aug. 27, a. m.	
(5.020)	2.113
3.884	2.315
3.072	2.466
2.354	2.631
1.712	2.841
1.285	2.951
Aug. 28, a. m.	
4.850	2.132
3.828	2.325
3.038	2.506
2.334	2.667
1.720	2.870
1.312	3.009
Aug. 29, a. m.	
4.926	2.254
3.875	2.418
3.067	2.564
2.352	2.755
1.720	2.933
1.314	3.050
Aug. 30, a. m.	
5.000	2.218
3.925	2.421
3.096	2.573
2.367	2.741

M.	R.
Aug. 30, a. m.	
1.730	2.920
1.330	3.021
Aug. 31, a. m.	
4.918	2.222
3.871	2.395
3.064	2.586
2.350	2.765
1.714	2.923
1.310	3.029
Sept. 1, a. m.	
4.912	2.093
3.867	2.289
3.061	2.445
2.366	2.647
1.730	2.845
1.322	2.902
Sept. 2, a. m.	
4.828	1.561
3.814	1.806
3.030	2.041
2.349	2.249
1.723	2.482
1.349	2.593
Sept. 3, a. m.	
4.828	1.708
3.813	1.904
3.029	2.115
2.349	2.326
1.740	2.534
1.332	2.725
Sept. 7, a. m.	
5.081	2.154
3.970	2.348
3.124	2.582
2.334	2.711
1.658	2.934
1.329	3.025

[1] To reduce readings of Pyrheliometer A. P. O. IV to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.511.

TABLE 21.—*Pyrheliometer readings, Mount Wilson, California, 1917*—Continued.

M.	R.
Sept. 8, a. m.	
5.080	2.149
3.972	2.334
3.160	2.495
2.464	2.710
1.675	2.928
1.335	3.046
Sept. 9, a. m.	
4.990	2.181
3.916	2.333
3.094	2.523
2.426	2.720
1.739	2.902
1.386	2.960
Sept. 11, a. m.	
5.000	2.072
3.921	2.238
3.097	2.398
2.430	2.560
1.814	2.760
1.349	2.902
Sept. 12, a. m.	
4.915	2.086
3.871	2.256
3.068	2.450
2.432	2.590
1.835	2.782
1.363	2.919

M.	R.
Sept. 13, a. m.	
5.006	2.172
3.927	2.313
3.135	2.469
2.493	2.625
1.868	2.852
1.376	2.989
Sept. 14, a. m.	
4.925	2.001
3.877	2.242
3.104	2.443
2.475	2.563
1.860	2.777
1.387	2.932
Sept. 15, a. m.	
4.927	2.014
3.880	2.267
3.107	2.443
2.458	2.571
1.853	2.771
1.393	2.909
Sept. 16, a. m.	
4.930	2.146
3.884	2.310
3.110	2.476
2.460	2.614
1.855	2.808
1.398	2.933

M.	R.
Sept. 17, a. m.	
5.020	2.110
3.938	2.273
3.113	2.426
2.464	2.604
1.848	2.767
1.397	2.957
Sept. 18, a. m.	
5.025	1.856
3.942	2.063
3.150	2.263
2.486	2.417
1.872	2.650
1.412	2.791
Sept. 19, a. m.	
4.948	1.744
3.896	1.921
3.120	2.142
2.489	2.313
1.864	2.517
1.416	2.703
Sept. 20, a. m.	
4.955	1.736
3.902	1.941
3.125	2.157
2.493	2.304
1.877	2.499
1.419	2.660

M.	R.
Sept. 22, a. m.	
4.888	2.158
3.859	2.347
3.101	2.501
2.480	2.621
1.827	2.799
1.414	2.936
Sept. 23, a. m.	
4.898	2.165
3.867	2.352
3.106	2.490
2.465	2.649
Sept. 24, a. m.	
4.825	2.032
3.824	2.221
3.079	2.374
2.451	2.584
1.844	2.726
1.465	2.771
Sept. 25, a. m.	
4.832	2.065
3.828	2.263
3.084	2.483
2.474	2.591
1.867	2.767
1.478	2.931

M.	R.
Sept. 26, a. m.	
5.000	2.131
3.935	2.297
3.153	2.439
2.497	2.618
1.870	2.790
1.367	2.959
Sept. 27, a. m.	
4.930	2.193
3.892	2.327
3.127	2.469
2.503	2.665
1.895	2.814
1.478	2.935
Sept. 30, a. m.	
5.043	2.092
3.915	2.265
3.114	2.454
2.390	2.629
1.800	2.771
1.390	2.877
Oct. 1, a. m.	
5.050	1.902
3.973	2.119
3.183	2.294
2.378	2.506
1.953	2.652
1.501	2.847

M.	R.
Oct. 2, a. m.	
5.058	1.955
3.980	2.126
3.190	2.336
2.528	2.527
1.817	2.710
1.461	2.839
Oct. 3, a. m.	
4.985	1.939
3.934	2.162
3.165	2.355
2.514	2.496
1.884	2.696
1.489	2.770
Oct. 6, a. m.	
4.938	2.139
3.912	2.341
3.154	2.473
2.514	2.640
1.920	2.807
1.526	2.985
Oct. 7, a. m.	
4.948	2.078
3.921	2.284
3.161	2.453
2.502	2.616
1.916	2.794
1.442	2.910

M.	R.
Oct. 8, a. m.	
4.881	1.822
3.882	2.045
3.170	2.207
2.528	2.386
1.923	2.558
1.524	2.745
Oct. 9, a. m.	
4.970	1.811
3.939	2.018
3.176	2.210
2.515	2.413
1.927	2.652
1.515	2.798

TABLE 22.—*Pyrheliometer readings, Mount Wilson, California, 1918.*

[Pyrheliometer A. P. O. IV[1]—Observer L. B. A.]

M.	R.
June 23, a. m.	
4.014	1.758
2.801	2.054
2.013	2.357
1.417	2.651
June 24, a. m.	
4.460	1.930
3.575	2.115
2.680	2.332
2.292	2.545
1.644	2.726
1.274	2.906
June 25, a. m.	
4.400	2.180
3.580	2.332
2.931	2.487
2.304	2.656
1.705	2.803
1.243	2.973

M.	R.
June 26, a. m.	
4.528	1.632
3.569	1.837
2.991	1.980
2.305	2.177
1.713	2.448
1.324	2.593
June 29, a. m.	
4.550	1.549
3.685	1.750
3.003	1.924
2.296	2.178
1.715	2.377
July 3, a. m.	
4.756	1.686
3.806	1.852
3.078	2.036
2.390	2.234

M.	R.
July 3, a. m.	
1.730	2.473
1.330	2.567
July 4, a. m.	
4.759	1.837
3.817	2.010
3.088	2.147
2.412	2.323
1.757	2.573
1.355	2.688
July 5, a. m.	
4.766	1.962
3.827	2.144
3.094	2.313
2.415	2.450
1.742	2.637
1.320	2.758

M.	R.
July 6, a. m.	
4.640	2.034
3.746	2.166
3.038	2.338
2.366	2.514
1.735	2.710
1.352	2.788
July 8, a. m.	
4.666	1.548
3.772	1.773
3.056	1.982
2.394	2.220
1.705	2.455
1.328	2.640
July 9, a. m.	
4.790	1.786
3.833	1.984

M.	R.
July 9, a. m.	
3.093	2.190
2.398	2.374
1.751	2.611
1.357	2.757
July 11, a. m.	
3.633	2.342
2.991	2.505
2.391	2.681
1.841	2.818
July 14, a. m.	
4.499	1.953
2.964	2.256
2.353	2.447
1.754	2.662
1.368	2.787

M.	R.
July 15, a. m.	
4.600	1.948
3.700	2.151
2.978	2.312
2.357	2.502
1.758	2.644
1.367	2.802
July 21, a. m.	
4.655	2.069
3.734	2.235
3.055	2.383
2.406	2.532
1.713	2.737
1.357	2.820
July 22, a. m.	
4.777	1.930
3.804	2.113
3.102	2.292

M.	R.
July 22, a. m.	
2.414	2.466
1.784	2.681
1.364	2.814
July 23, a. m.	
4.619	2.098
3.931	2.232
3.052	2.397
2.389	2.552
1.760	2.751
1.358	2.842
July 24, a. m.	
4.775	2.145
3.807	2.297
3.105	2.441
2.378	2.638
1.728	2.814
1.352	2.915

[1] To reduce readings of Pyrheliometer A. P. O. IV to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.511.

TABLE 22.—*Pyrheliometer readings, Mount Wilson, California, 1918*—Continued.

M.	R.
July 25, a. m.	
4. 627	2. 140
3. 696	2. 312
3. 024	2. 446
2. 388	2. 603
1. 751	2. 810
1. 359	2. 935
July 26, a. m.	
4. 967	2. 120
3. 861	2. 332
3. 138	2. 446
2. 433	2. 637
1. 784	2. 830
1. 357	2. 978
July 27, a. m.	
4. 838	2. 290
3. 839	2. 466
3. 123	2. 565
2. 464	2. 718
1. 778	2. 945
1. 363	3. 058
July 28, a. m.	
4. 882	2. 104
3. 869	2. 297
3. 139	2. 487
2. 455	2. 646
1. 793	2. 802
1. 369	2. 905
July 29, a. m.	
4. 777	1. 733
3. 948	1. 920
3. 095	2. 075
2. 445	2. 231
1. 788	2. 455
1. 305	2. 633
Aug. 2, a. m.	
4. 896	1. 856
3. 855	2. 027
3. 139	2. 174
2. 431	2. 348
1. 762	2. 537
1. 352	2. 665
Aug. 3, a. m.	
4. 804	1. 484
3. 676	1. 705
2. 686	2. 013
1. 858	2. 327
1. 380	2. 553
Aug. 4, a. m.	
5. 015	1. 614
3. 947	1. 840
3. 184	2. 029
2. 480	2. 233
1. 795	2. 443
1. 358	2. 665
Aug. 5, a. m.	
4. 894	2. 062
3. 898	2. 250
3. 139	2. 406
2. 431	2. 580
1. 781	2. 771
1. 300	2. 896
Aug. 6, a. m.	
4. 848	2. 179
3. 893	2. 347
3. 063	2. 471
2. 427	2. 629
Aug. 8, a. m.	
4. 921	2. 155
3. 885	2. 307
3. 143	2. 416
2. 471	2. 644
1. 820	2. 770
1. 317	2. 933
Aug. 9, a. m.	
4. 891	2. 005
3. 878	2. 155
3. 136	2. 347
2. 467	2. 485
1. 817	2. 686
1. 334	2. 787
Aug. 10, a. m.	
4. 729	1. 852
3. 761	1. 995
3. 063	2. 210
2. 422	2. 381
1. 784	2. 557
Aug. 11, a. m.	
4. 933	1. 710
3. 898	1. 886
3. 149	2. 084
2. 475	2. 302
1. 773	2. 510
1. 355	2. 681
Aug. 12, a. m.	
4. 932	1. 621
3. 888	1. 808
3. 152	1. 986
2. 451	2. 208
1. 780	2. 473
1. 356	2. 657
Aug. 13, a. m.	
4. 916	1. 770
3. 876	1. 951
3. 105	2. 119
2. 447	2. 317
1. 780	2. 577
1. 385	2. 732
Aug. 14, a. m.	
4. 902	1. 883
3. 818	2. 138
3. 094	2. 290
2. 461	2. 451
1. 797	2. 632
1. 364	2. 870
Aug. 19, a. m.	
4. 854	2. 039
3. 819	2. 244
3. 064	2. 424
2. 381	2. 592
1. 732	2. 769
1. 362	2. 881
Aug. 20, a. m.	
4. 789	2. 119
3. 814	2. 324
3. 059	2. 483
2. 400	2. 642
1. 757	2. 818
1. 360	2. 908
Aug. 21, a. m.	
4. 794	2. 187
3. 806	2. 376
3. 055	2. 532
2. 361	2. 693
1. 730	2. 898
1. 273	3. 021
Aug. 22, a. m.	
4. 803	2. 168
3. 801	2. 355
3. 050	2. 516
2. 376	2. 680
1. 730	2. 842
1. 350	2. 950
Aug. 23, a. m.	
4. 867	1. 987
3. 844	2. 209
3. 077	2. 357
2. 393	2. 530
1. 754	2. 695
1. 366	2. 895
Aug. 29, a. m.	
4. 904	1. 788
3. 867	1. 993
3. 093	2. 168
2. 420	2. 355
1. 771	2. 546
Sept. 1, a. m.	
4. 821	2. 069
3. 808	2. 251
3. 065	2. 438
2. 399	2. 614
1. 763	2. 802
1. 317	2. 911
Sept. 2, a. m.	
4. 899	1. 926
3. 858	2. 116
3. 087	2. 312
Sept. 5, a. m.	
4. 897	2. 083
3. 855	2. 234
3. 084	2. 413
2. 400	2. 555
1. 748	2. 784
1. 365	2. 892
Sept. 6, a. m.	
4. 981	1. 844
3. 907	2. 109
3. 118	2. 291
2. 458	2. 439
1. 795	2. 617
1. 379	2. 812
Sept. 9, a. m.	
4. 899	2. 096
3. 857	2. 300
3. 120	2. 438
2. 480	2. 553
1. 729	2. 742
1. 384	2. 874
Sept. 16, a. m.	
5. 000	1. 980
3. 925	2. 164
3. 166	2. 322
2. 494	2. 539
1. 824	2. 757
1. 410	2. 847
Sept. 19, a. m.	
5. 099	2. 200
3. 991	2. 372
3. 212	2. 503
2. 504	2. 724
1. 842	2. 898
1. 422	3. 015
Sept. 20, a. m.	
5. 025	2. 200
3. 943	2. 391
3. 181	2. 542
2. 486	2. 731
1. 846	2. 889
1. 417	3. 031
Sept. 24, a. m.	
5. 138	2. 071
4. 016	2. 323
3. 233	2. 480
2. 541	2. 621
1. 860	2. 811
1. 464	2. 945
Sept. 25, a. m.	
5. 060	1. 944
3. 968	2. 144
3. 204	2. 341
2. 566	2. 524
1. 844	2. 779
1. 465	2. 889
Sept. 26, a. m.	
5. 070	2. 111
3. 977	2. 316
3. 210	2. 462
2. 570	2. 630
1. 881	2. 826
1. 463	3. 028
Oct. 2, a. m.	
4. 958	2. 086
3. 918	2. 237
3. 181	2. 352
2. 543	2. 554
Oct. 9, a. m.	
4. 956	2. 056
3. 928	2. 232
3. 199	2. 380
2. 606	2. 506
1. 457	2. 921
Oct. 10, a. m.	
5. 048	2. 115
3. 991	2. 298
3. 240	2. 455
2. 593	2. 631
1. 930	2. 788
1. 480	2. 935
Oct. 11, a. m.	
5. 143	2. 087
4. 054	2. 274
3. 318	2. 435
2. 641	2. 656
1. 974	2. 794
1. 501	2. 964
Oct. 12, a. m.	
5. 070	1. 945
4. 011	2. 166
2. 930	2. 397
2. 529	2. 534
1. 923	2. 716
1. 517	2. 851

TABLE 23.—*Pyrheliometer readings, Mount Wilson, California, 1919.*

[Pyrheliometer A. P. O. IV[1]—Observer L. B. A.]

M.	R.
June 15 a. m.	
4.300	2.011
3.510	2.190
2.781	2.367
2.212	2.509
1.448	2.785
June 16, a. m.	
4.546	2.025
3.675	2.203
2.994	2.370
2.324	2.567
1.689	2.778
1.270	2.894
June 17, a. m.	
4.475	2.140
3.627	2.325
3.021	2.485
2.339	2.663
1.714	2.817
1.270	2.958
June 18, a. m.	
4.405	2.102
3.580	2.256
2.932	2.432
2.271	2.612
1.680	2.799
1.288	2.942
June 19, a. m.	
4.162	2.072
3.419	2.254
2.824	2.403
June 21, a. m.	
3.996	2.185
3.310	2.327
2.745	2.462
2.147	2.661
1.596	2.804
1.223	2.980
June 22, a. m.	
4.461	2.180
3.618	2.302
2.957	2.433
2.370	2.621
1.731	2.772
1.284	2.919
June 23, a. m.	
4.216	2.179
3.455	2.373
2.847	2.468

M.	R.
June 23, a. m.	
2.269	2.625
1.671	2.775
1.273	2.908
June 24, a. m.	
4.399	2.098
3.577	2.271
2.930	2.399
2.269	2.570
1.696	2.742
1.295	2.879
June 25, a. m.	
4.340	2.111
3.538	2.257
2.903	2.403
1.898	2.657
1.325	2.832
June 26, a. m.	
4.470	1.855
3.625	2.055
2.962	2.219
2.256	2.435
1.688	2.620
1.319	2.723
June 27, a. m.	
4.543	2.009
3.673	2.185
2.993	2.343
2.257	2.561
1.689	2.717
1.328	2.843
June 28, a. m.	
4.546	2.063
3.677	2.202
2.995	2.348
2.325	2.548
1.706	2.722
1.285	2.878
June 29, a. m.	
4.560	2.042
3.683	2.191
2.999	2.380
2.360	2.524
1.724	2.744
1.324	2.898
June 30, a. m.	
4.570	2.158
3.688	2.329
3.002	2.448

M.	R.
June 30, a. m.	
2.362	2.603
1.752	2.800
1.342	2.931
July 1, a. m.	
4.653	2.102
3.741	2.250
3.036	2.400
2.383	2.570
1.607	2.820
1.286	2.918
July 2, a. m.	
4.738	2.035
3.795	2.186
3.072	2.356
2.424	2.531
1.764	2.708
1.342	2.792
July 3, a. m.	
4.824	1.956
3.854	2.092
3.078	2.292
2.390	2.476
1.756	2.668
1.361	2.819
July 6, a. m.	
4.873	1.947
3.885	2.108
3.128	2.284
2.437	2.477
1.780	2.666
1.368	2.838
July 7, a. m.	
4.975	1.899
3.948	2.079
3.170	2.234
2.461	2.462
1.782	2.619
1.325	2.807
July 9, a. m.	
4.716	1.550
3.781	1.769
3.061	1.965
2.342	2.161
1.698	2.520
1.331	2.655
July 10, a. m.	
4.665	1.905
3.749	2.098

M.	R.
July 10, a. m.	
3.038	2.248
2.313	2.434
1.708	2.606
1.333	2.687
July 11, a. m.	
4.550	1.667
3.672	1.832
2.988	2.027
2.318	2.227
1.711	2.403
1.329	2.572
July 14, a. m.	
4.850	1.654
3.864	1.848
3.112	2.066
2.387	2.278
1.753	2.511
1.305	2.667
July 20, a. m.	
4.906	1.541
3.897	1.712
3.128	1.863
2.376	2.109
July 21, a. m.	
4.946	1.606
3.919	1.792
3.142	1.968
2.367	2.210
1.724	2.506
1.345	2.651
July 22, a. m.	
4.910	1.885
3.896	2.023
3.127	2.198
2.340	2.428
1.728	2.598
1.351	2.798
July 23, a. m.	
4.874	1.554
3.872	1.731
3.112	1.923
2.384	2.174
1.740	2.391
1.359	2.570
July 24, a. m.	
4.994	1.524
3.948	1.730
3.161	1.938

M.	R.
July 24, a. m.	
2.430	2.150
1.762	2.387
1.326	2.548
July 27, a. m.	
5.058	1.443
3.985	1.685
3.181	1.913
2.479	2.073
1.767	2.408
1.363	2.580
July 29, a. m.	
4.994	2.113
3.042	2.307
3.153	2.460
2.443	2.646
1.741	2.880
1.359	3.002
July 30, a. m.	
4.964	2.174
3.922	2.360
3.139	2.516
2.434	2.661
1.764	2.873
1.370	2.982
July 31, a. m.	
4.938	2.148
3.903	2.319
3.126	2.454
2.446	2.664
1.778	2.810
1.300	3.006
Aug. 1, a. m.	
4.990	1.851
3.937	2.090
3.146	2.265
2.420	2.431
1.756	2.630
1.363	2.779
Aug. 2, a. m.	
4.968	2.134
3.919	2.273
3.136	2.443
2.412	2.648
1.752	2.788
1.367	2.948
Aug. 3, a. m.	
4.943	2.143
3.902	2.280

M.	R.
Aug. 3, a. m.	
3.125	2.465
2.462	2.591
1.758	2.794
1.360	2.938
Aug. 4, a. m.	
4.918	2.124
3.887	2.294
3.113	2.449
2.417	2.644
1.746	2.814
1.361	2.944
Aug. 5, a. m.	
(4.975)	2.085
3.921	2.203
3.134	2.413
2.448	2.538
1.770	2.758
1.345	2.913
Aug. 7 a,. m.	
4.927	1.681
3.890	1.931
3.113	2.082
2.435	2.235
1.763	2.428
1.326	2.630
Aug. 10, a. m.	
4.948	2.023
3.900	2.219
3.118	2.411
2.398	2.576
1.747	2.762
1.352	2.880
Aug. 11, a. m.	
4.621	2.101
3.696	2.218
2.987	2.422
2.306	2.618
Aug. 12, a. m.	
4.917	2.070
3.878	2.250
3.102	2.382
2.487	2.535
2.020	2.680
1.363	2.885
Aug. 13, a. m.	
4.897	2.064
3.866	2.202
3.095	2.366

M.	R.
Aug. 13, a. m.	
2.481	2.534
2.042	2.692
1.415	2.851
Aug. 14, a. m.	
4.884	2,076
3.856	2.233
3.088	2.408
2.517	2.565
2.039	2.673
1,394	2.868
Aug. 19, a. m.	
4.897	1.680
3.862	1.857
3.090	2.050
2.518	2.229
2.041	2.373
1.402	2.617
Aug. 22, a. m.	
4.865	1.526
3.839	1.762
3.075	1.958
2.469	2.134
2.022	2.307
1.396	2.554
Aug. 23, a. m.	
4.776	1.546
3.782	1.791
2.979	1.978
2.466	2.165
2.008	2.407
1.378	2.621
Aug. 27, a. m.	
4.745	0.872
3.761	1.126
3.026	1.306
2.497	1.553
2.014	1.884
1.385	2.110
Aug. 28, a. m.	
4.881	1.164
3.807	1.397
3.055	1.587
2.495	1.807
2.040	2.026
1.388	2.332
Aug. 29, a. m.	
4.917	1.440
3.106	1.664

[1] To reduce readings of Pyrheliometer A. P. O. IV to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.511.

TABLE 23.—*Pyrheliometer readings, Mount Wilson, California, 1919*—Continued.

M.	R.
Aug. 29, a. m.	
3.054	1.900
2.494	2.066
2.028	2.233
1.401	2.526
Aug. 30, a. m.	
4.893	1.389
3.854	1.674
3.082	1.890
2.534	2.047
2.040	2.241
Sept. 1, a. m.	
4.884	1.805
3.848	2.029
3.080	2.279
2.513	2.400
2.027	2.557
1.425	2.769

M.	R.
Sept. 2, a. m.	
4.882	2.068
3.847	2.274
3.080	2.437
2.511	2.568
2.040	2.716
1.437	2.887
Sept. 3, a. m.	
4.964	1.963
3.898	2.138
3.112	2.328
2.534	2.492
2.027	2.616
1.429	2.822
Sept. 4, a. m.	
4.962	2.176
3.896	2.387
3.110	2.537

M.	R.
Sept. 4, a. m.	
2.533	2.664
2.055	2.823
1.435	2.972
Sept. 5, a. m.	
4.880	2.184
3.843	2.359
3.077	2.520
2.513	2.665
2.029	2.825
1.422	2.990
Sept. 6, a. m.	
4.959	2.115
3.892	2.270
3.108	2.460
2.533	2.573
2.043	2.726
1.425	2.910

M.	R.
Sept. 7, a. m.	
4.962	2.056
3.896	2.258
3.110	2.446
2.535	2.576
2.044	2.705
1.435	2.894
Sept. 8, a. m.	
4.958	2.036
3.894	2.183
3.110	2.373
2.535	2.558
2.045	2.634
1.414	2.854
Sept. 11, a. m.	
4.882	2.094
3.846	2.306
3.082	2.437

M.	R.
Sept. 11, a. m.	
2.518	2.640
2.050	2.749
1.416	2.998
Sept. 12, a. m.	
4.970	2.153
3.900	2.372
3.116	2.536
2.541	2.676
2.052	2.821
1.427	2.983
Sept. 13, a. m.	
4.971	2.027
3.904	2.220
3.119	2.352
2.543	2.481
2.054	2.655
1.440	2.840

M.	R.
Sept. 16, a. m.	
4.983	1.935
3.912	2.125
3.125	2.301
2.550	2.457
2.036	2.629
1.408	2.816
Sept. 17, a. m.	
4.987	2.183
3.916	2.329
3.128	2.499
2.552	2.625
2.076	2.785
1.437	2.927
Sept. 18, a. m.	
4.993	1.896
3.918	2.091
3.132	2.266
2.555	2.412
1.959	2.583
1.440	2.789

M.	R.
Sept. 19, a. m.	
4.996	1.690
3.922	1.899
3.135	2.129
2.558	2.286
1.962	2.465
1.452	2.696
Sept. 20, a. m.	
4.920	1.705
3.875	1.925
3.107	2.117
2.542	2.330
1.954	2.525
1.442	2.704
Sept. 21 a. m.	
5.011	1.907
3.934	2.106
3.143	2.278
2.566	2.443
2.063	2.618

TABLE 24.—*Pyrheliometer readings, Mount Wilson, California, 1920.*

[Pyrheliometer A. P. O. IV[1]—Observers C. G. A. and L. B. A.]

M.	R.
July 8, a. m.	
4.195	2.159
3.974	2.179
3.557	2.233
2.913	2.378
2.375	2.507
1.866	2.705
1.376	2.810
July 9, a. m.	
4.271	2.212
3.611	2.316
3.007	2.447
2.475	2.561
1.936	2.739
1.373	2.929
July 10, a. m.	
4.292	2.104
3.670	2.221
3.046	2.354
2.543	2.487
1.961	2.657
1.399	2.834
July 11, a. m.	
4.311	2.276
3.682	2.375
3.117	2.476

M.	R.
July 11, a. m.	
2.548	2.606
1.964	2.755
1.398	2.957
July 12, a. m.	
4.461	2.226
3.746	2.370
3.162	2.521
2.577	2.659
1.968	2.775
1.344	2.953
July 13, a. m.	
4.420	2.165
3.713	2.282
3.140	2.396
2.584	2.536
1.984	2.659
1.386	2.895
July 14, a. m.	
4.261	2.141
3.646	2.238
3.089	2.369
2.528	2.468
1.941	2.631
1.351	2.860

M.	R.
July 17, a. m.	
4.161	2.001
3.570	2.196
3.035	2.358
2.532	2.452
1.898	2.637
1.331	2.808
July 18, a. m.	
4.132	2.200
3.548	2.282
3.018	2.384
2.520	2.513
1.924	2.703
1.348	2.807
July 19, a. m.	
4.157	2.337
3.565	2.403
3.030	2.528
2.508	2.643
1.884	2.831
1.321	2.950
July 20, a. m.	
4.306	2.184
3.676	2.353
3.076	2.469

M.	R.
Iuly 20, a. m.	
2.539	2.581
1.969	2.728
1.327	2.875
July 21, a. m.	
4.276	2.001
3.608	2.086
3.030	2.216
2.527	2.312
1.939	2.489
1.356	2.694
July 24, a. m.	
4.312	1.914
3.677	2.066
3.076	2.192
2.536	2.343
1.955	2.526
1.361	2.728
July 25, a. m.	
4.410	2.021
3.703	2.180
3.126	2.261
2.569	2.437
1.997	2.613
1.341	2.795

M.	R.
July 26, a. m.	
4.384	2.047
3.728	2.166
3.209	2.279
2.560	2.433
1.944	2.615
1.899	2.624
1.349	2.801
July 28, a. m.	
4.532	1.870
3.834	1.989
3.116	2.176
2.562	2.344
1.968	2.507
1.354	2.724
July 29, a. m.	
4.191	1.848
3.584	1.968
3.102	2.070
2.552	2.251
2.011	2.407
1.357	2.581
Aug. 3, a. m.	
4.331	1.632
3.686	1.748

M.	R.
Aug. 3, a. m.	
3.108	1.903
2.576	2.087
1.999	2.318
1.332	2.594
Aug. 4, a. m.	
4.508	1.979
3.762	2.120
3.162	2.266
2.635	2.398
1.994	2.561
1.376	2.782
Aug. 5, a. m.	
4.487	2.124
3.796	2.243
3.152	2.397
2.583	2.535
1.898	2.709
1.355	2.874
Aug. 7, a. m.	
3.721	2.034
3.132	2.190
2.591	2.312
1.995	2.493
1.345	2.710

M.	R.
Aug. 8, a. m.	
4.644	1.628
3.905	1.744
3.223	1.925
2.541	1.981
1.943	2.280
1.364	2.530
Aug. 9, a. m.	
4.623	1.956
3.839	2.049
3.178	2.220
2.454	2.410
1.763	2.569
1.281	2.753
Aug. 12, a. m.	
4.724	1.730
3.960	1.891
3.295	2.016
2.562	2.226
2.002	2.451
1.398	2.615
Aug. 13, a. m.	
4.561	1.498
3.844	1.750

[1] To reduce readings of Pyrheliometer A. P. O. IV to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.511.

Table 24.—*Pyrheliometer readings, Mount Wilson, California, 1920*—Continued.

M.	R.
Aug. 13, a. m.	
3.214	1.831
2.622	2.025
1.961	2.366
1.323	2.538
Aug. 14, a. m.	
4.480	1.439
3.787	1.575
3.173	1.727
2.594	1.918
1.972	2.156
1.324	2.479
Aug. 15, a. m.	
4.404	1.360
3.683	1.596
3.101	1.778
2.547	1.960
1.958	2.129
1.327	2.481
Aug. 16, a. m.	
4.386	1.605
3.673	1.807
3.029	1.968
2.520	2.129
1.943	2.316
1.331	2.605
Aug. 17, a. m.	
5.140	1.454
3.964	1.712
3.223	1.912
2.697	2.105
2.080	2.318
1.373	2.627
Aug. 18, a. m.	
4.511	2.147
3.752	2.295
3.149	2.385
2.557	2.570
1.987	2.713
1.332	2.937
Aug. 19, a. m.	
4.484	2.279
3.792	2.382
3.176	2.507
2.551	2.656
1.949	2.795
1.334	2.981
Aug. 20, a. m.	
4.416	2.163
3.737	2.282
3.137	2.427
2.446	2.572
1.818	2.796
1.332	2.949
Aug. 21, a. m.	
4.542	2.104
3.684	2.253
3.100	2.395
2.463	2.556
1.827	2.753
1.289	2.926
Aug. 22, a. m.	
4.536	2.180
3.822	2.330
3.196	2.475
2.384	2.699
1.796	2.850
1.306	3.020
Aug. 23, a. m.	
4.527	1.932
2.767	2.054
3.158	2.150
2.458	2.385
Aug. 27, a. m.	
4.574	2.216
3.796	2.343
3.177	2.468
2.431	2.626
1.853	2.805
1.256	2.956
Aug. 29, a. m.	
4.793	2.039
4.360	2.075
3.649	2.213
3.076	2.335
2.530	2.505
1.929	2.671
1.285	2.843
Aug. 30, a. m.	
4.421	1.916
3.738	2.070
3.105	2.222
2.508	2.378
1.975	2.605
1.429	2.773
Sept. 2, a. m.	
4.483	1.826
3.781	1.983
3.135	2.116
2.528	2.263
1.919	2.446
1.375	2.672
Sept. 3, a. m.	
4.481	1.579
3.780	1.718
3.167	1.849
2.390	2.045
1.865	2.291
1.334	2.534
1.320	2.535
Sept. 4, a. m.	
4.099	1.994
3.549	2.107
2.977	2.277
2.337	2.434
1.836	2.615
1.343	2.720
1.330	2.744
Sept. 5, a. m.	
4.482	2.043
3.781	2.230
3.168	2.326
2.487	2.499
1.746	2.724
1.330	2.836
Sept. 6, a. m.	
4.552	2.218
3.830	2.358
3.133	2.458
2.508	2.601
1.922	2.773

Table 25.—*Pyrheliometer readings, Hump Mountain, North Carolina, 1917.*

[Pyrheliometer S. I. 30[1]—Observers A. F. M. and L. H. A.]

M.	R.
June 17, a. m.	
4.41	3.068
3.59	3.287
2.73	3.512
2.30	3.653
1.81	3.853
1.55	4.007
June 18, a. m.	
4.87	2.196
4.01	2.568
3.35	2.808
2.72	3.039
2.07	3.292
1.35	3.639
June 30, a. m.	
4.41	2.756
3.70	2.959
3.07	3.151
2.47	3.409
1.79	3.726
1.24	3.877
July 1, a. m.	
4.92	2.350
4.08	2.700
3.28	2.930
2.73	3.081
2.09	3.298
1.32	3.818
July 2, a. m.	
4.99	2.070
4.10	2.366
3.39	2.647
2.73	2.928
2.04	3.243
1.45	3.556
July 10, a. m.	
4.78	2.507
4.13	2.754
3.51	2.771
2.78	2.707
2.02	2.711
1.37	2.820
Aug. 4, a. m.	
4.64	2.477
3.97	2.698
3.39	2.903
2.76	3.148
1.99	3.674
1.25	3.813
Aug. 6, a. m.	
4.69	2.081
4.04	2.313
3.40	2.563
2.73	2.855
2.01	3.207
Aug. 11, a. m.	
4.70	1.761
4.03	2.166
3.39	2.408
2.70	2.804
2.00	3.114
Aug. 18, a. m.	
4.39	2.877
4.17	3.052
3.34	3.188
2.69	3.504
2.03	3.722
1.30	3.942
Aug. 25, a. m.	
4.74	2.563
4.03	2.839
3.36	3.123
2.73	3.413
Aug. 26, a. m.	
4.74	3.076
4.04	3.201
3.40	3.367
2.67	3.607
1.97	3.849
1.25	4.108
Aug. 28, a. m.	
4.75	1.988
4.00	2.237
3.29	2.517
2.65	2.785
1.97	3.135
Sept. 12, a. m.	
4.91	2.822
4.09	3.105
3.33	3.297
2.71	3.514
2.02	3.755
1.31	4.152
Sept. 13, a. m.	
4.34	3.156
4.12	3.313
3.31	3.503
2.65	3.750
1.98	4.039
1.32	4.259
Sept. 18, a. m.	
4.75	2.820
4.07	3.007
3.36	3.216
2.71	3.444
2.03	3.738
1.30	4.083
Sept. 26, a. m.	
4.82	2.597
4.11	2.785
3.35	3.044
2.72	3.293
2.11	3.535
1.35	3.842
Oct. 2, a. m.	
4.74	3.048
4.05	3.195
3.37	3.413
2.73	3.648
2.06	3.873
1.32	4.095
Oct. 3, a. m.	
3.38	3.340
2.91	3.497
2.41	3.703
1.87	3.925
Oct. 5, a. m.	
4.94	2.699
4.20	2.927
3.45	3.152
2.80	3.374
2.05	3.698
1.36	3.858
Oct. 10, a. m.	
5.02	2.884
4.28	3.032
3.48	3.304
2.74	3.512
2.04	3.802
Oct. 13, a. m.	
4.83	3.095
4.13	3.329
3.29	3.591
2.71	3.765
2.03	4.013
1.39	4.221
Oct. 14, a. m.	
5.05	2.628
4.35	2.815
3.67	3.012
3.08	3.255
2.37	3.590
1.60	3.741
Oct. 15, a. m.	
4.94	2.512
4.21	2.639
3.53	2.877
2.75	3.203
2.01	3.569
Oct. 16, a. m.	
4.97	2.585
4.30	2.736
3.51	3.010
2.77	3.283
2.04	3.539
1.42	3.833
Oct. 20, p. m.	
1.63	4.212
2.29	3.881
2.96	3.587
3.66	3.326

[1] To reduce readings of Pyrheliometer S. I. 30 to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.3605.

TABLE 25.—*Pyrheliometer readings, Hump Mountain, North Carolina, 1917*—Continued.

M.	R.
Oct. 21, a. m.	
5.05	3.032
4.30	3.170
3.49	3.428
2.77	3.610
2.03	3.841
1.47	4.083
Oct. 22, a. m.	
4.30	2.849
3.62	3.125
3.14	3.304
2.54	3.573
2.00	3.845
1.48	4.056
Oct. 28, a. m.	
5.04	3.107
4.31	3.277
3.38	3.541
Oct. 28, a. m.	
2.76	3.754
2.09	4.007
1.53	4.298
Nov. 4, a. m.	
5.06	3.044
4.35	3.231
3.53	3.444
2.83	3.703
2.17	3.933
1.61	4.236
Nov. 5, a. m.	
4.99	3.153
4.36	3.307
3.58	3.416
2.86	3.680
2.18	3.955
1.62	4.199
Nov. 6, a. m.	
4.97	2.966
4.31	3.105
3.61	3.287
2.89	3.495
2.16	3.829
1.63	3.992
Nov. 7, a. m.	
5.03	2.589
4.33	2.788
3.59	3.045
2.93	3.365
2.18	3.661
1.64	3.971
Nov. 8, a. m.	
4.99	2.959
4.32	3.149
3.52	3.414
2.71	3.667
Nov. 8, a. m.	
2.13	3.927
1.66	4.012
Nov. 9, p. m.	
1.67	3.972
2.49	3.330
3.12	3.012
3.67	2.750
Nov. 10, a. m.	
5.05	2.263
4.36	2.473
3.59	2.578
2.91	2.989
2.16	3.455
1.68	3.495
Nov. 11, a. m.	
5.16	2.589
4.49	2.784
Nov. 11, a. m.	
3.75	2.982
3.21	3.265
2.63	3.392
Nov. 15, a. m.	
5.07	2.839
4.39	2.827
3.58	3.297
2.94	3.511
2.12	3.992
1.73	3.849
Nov. 17, a. m.	
5.01	3.132
4.41	3.282
3.64	3.510
2.92	3.737
2.15	4.035
1.75	4.145
Nov. 18, a. m.	
5.05	3.128
4.44	3.274
3.66	3.487
2.98	3.690
2.30	3.911
1.77	4.031
Nov. 26, p. m.	
1.89	4.176
2.43	3.945
3.06	3.653
3.87	3.375
4.43	3.221
Dec. 17, p. m.	
1.98	4.155
2.58	3.789
3.20	3.428
3.82	3.267
Dec. 17, p. m.	
4.42	3.102
4.97	2.953
Dec. 19, a. m.	
4.67	3.156
4.15	3.312
3.56	3.487
3.05	3.654
2.50	3.890
2.02	4.051
Dec. 20, a. m.	
5.01	3.010
4.40	3.183
3.68	3.365
3.22	3.566
2.57	3.750
1.98	3.942

TABLE 26.—*Pyrheliometer readings, Hump Mountain, North Carolina, 1918.*

[Pyrheliometer S. I. 30[1]—Observers A. F. M. and L. H. A.]

M.	R.
Jan. 10, p. m.	
1.95	4.167
2.59	3.826
3.25	3.593
3.93	3.361
4.79	3.099
Jan. 12, a. m.	
4.54	3.498
3.95	3.642
3.24	3.857
2.66	4.060
1.91	4.315
Feb. 4, p. m.	
1.75	4.258
2.41	4.001
Feb. 4, p. m.	
3.07	3.753
3.79	3.471
4.45	3.289
Feb. 6, a. m.	
5.04	2.953
4.34	3.146
3.56	3.234
3.03	3.574
Feb. 10, p. m.	
1.66	3.969
2.43	3.624
3.06	3.354
3.72	3.058
4.32	2.873
Feb. 11, a. m.	
5.15	2.754
4.41	2.867
3.70	3.108
3.02	3.381
2.31	3.693
1.59	4.013
Feb. 17, a. m.	
4.92	3.230
4.22	3.428
3.56	3.588
2.93	3.782
2.26	4.078
Feb. 18, a. m.	
5.08	2.964
4.33	3.151
Feb. 18, a. m.	
3.60	3.405
2.92	3.656
2.26	3.932
1.52	3.955
Feb. 23, a. m.	
4.98	3.285
4.27	3.429
3.53	3.611
2.87	3.835
2.09	4.104
1.44	4.362
Feb. 26, p. m.	
1.47	4.290
2.05	4.055
Feb. 26, p. m.	
2.62	3.775
3.23	3.617
3.78	3.393
Feb. 28, a. m.	
5.00	2.740
4.27	2.920
3.56	3.170
2.85	3.369
2.14	3.622
1.42	3.738
Mar. 2, a. m.	
5.03	2.987
4.27	3.167
3.53	3.390
Mar. 2, a. m.	
2.85	3.525
2.10	3.928
Mar. 8, a. m.	
4.97	3.140
4.22	3.350
3.48	3.565
2.86	3.791
2.08	4.123
1.46	4.367
Mar. 11, a. m.	
4.14	3.252
3.62	3.398
3.05	3.574
2.56	3.724
Mar. 11, a. m.	
1.95	3.977
1.35	4.295
Mar. 18, a. m.	
4.87	3.295
4.14	3.462
3.45	3.664
2.75	3.895
2.01	4.145
1.39	4.307

[1] To reduce readings of Pyrheliometer S. I. 30 to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.3605.

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TABLE 27.—*Pyrheliometer readings, Calama, Chile, 1918.*

[Pyrheliometer S. I. 30[1]—Observers A. F. M. and L. H. A.]

M.	R.	M.	R.	M.	R.	M.	R.	M.	R.	M.	R.	M.	R.
July 27, a. m.		Aug. 4, a. m.		Aug. 14, p. m.		Aug. 22, a. m.		Aug. 29, a. m.		Sept. 9, a. m.		Sept. 21 p. m.	
4.98	3.037	4.44	3.206	1.28	4.215	4.99	3.132	4.95	2.698	4.98	3.203	5.40	2.881
4.20	3.240	3.70	3.406	2.05	3.910	4.66	3.371	4.17	2.934	4.13	3.412	4.59	3.067
3.51	3.454	3.16	3.535	2.91	3.558	3.44	3.585	3.41	3.192	3.45	3.604	3.89	3.267
2.84	3.621	2.55	3.754	3.69	3.384	2.80	3.797	2.79	3.425	2.81	3.796	3.27	3.451
2.08	3.932	2.01	4.092	4.44	3.528	2.09	4.022	2.07	3.933	2.04	4.140	2.14	3.832
1.36	4.240	1.34	4.330	5.39	2.934	1.30	4.383	1.23	4.086	1.26	4.276	1.25	4.251
July 28, a. m.		Aug. 5, a. m.		Aug. 15, a. m.		Aug. 23, a. m.		Aug. 30, a. m.		Sept. 14, a. m.		Sept. 22 a. m.	
5.03	2.822	5.10	3.139	4.99	2.992	5.00	3.196	4.96	2.672	4.84	3.112	4.82	2.875
4.16	3.040	4.27	3.356	4.16	3.227	4.18	3.425	4.12	2.903	4.15	3.258	4.13	3.062
3.49	3.246	3.45	3.551	3.46	3.351	3.45	3.621	3.44	3.743	3.41	3.479	3.45	3.286
2.82	3.473	2.70	3.801	2.80	3.683	2.78	3.837	2.79	3.389	2.76	3.675	2.71	3.551
2.06	3.798	2.05	4.075	2.05	3.959	2.04	4.115	2.06	3.714	1.98	3.992	2.02	3.833
1.36	4.084	1.32	4.329	1.27	4.323	1.24	4.461	1.27	4.058	1.29	4.278	1.27	4.199
July 29, a. m.		Aug. 7, a. m.		Aug. 16, a. m.		Aug. 24, a. m.		Aug. 31 p. m.		Sept. 15, a. m.		Sept. 26, a. m.	
5.03	2.900	4.99	3.351	5.00	3.115	4.92	3.091	1.25	4.160	4.94	3.081	4.87	3.232
4.23	3.095	4.18	3.396	4.18	3.300	4.10	3.255	2.22	3.693	4.23	3.301	4.17	3.392
3.52	3.285	3.45	3.561	3.47	3.565	3.40	3.433	2.98	3.305	3.45	3.541	3.46	3.587
2.81	3.507	2.80	3.791	2.80	3.800	2.74	3.697	3.60	3.115	2.70	3.786	2.72	3.874
2.10	3.781	2.08	4.028	2.04	4.083	2.02	4.001	4.28	2.913	2.02	4.083	2.07	4.123
1.34	4.158	1.32	4.363	1.27	4.303	1.25	4.417	5.08	2.600	1.28	4.350	1.24	4.424
July 30, a. m.		Aug. 8, a. m.		Aug. 17, a. m.		Aug. 25, a. m.		Sept. 1, a. m.		Sept. 16, a. m.		Sept. 27 a. m.	
4.23	3.122	4.95	3.206	4.96	2.996	5.81	3.102	4.57	3.031	4.97	3.247	4.98	3.178
3.52	3.317	4.14	3.432	4.14	3.189	4.17	3.321	3.85	3.211	4.24	3.441	4.24	3.379
2.84	3.542	3.41	3.584	3.40	3.427	3.48	3.517	3.24	3.393	3.46	3.685	3.51	3.589
2.11	3.802	2.77	3.849	2.81	3.599	2.78	3.819	2.68	3.617	2.75	3.889	2.71	3.834
1.39	3.977	2.08	4.062	2.08	3.827	2.25	4.042	2.01	3.904	2.02	4.194	2.00	4.110
		1.33	4.394	1.26	4.066	1.26	4.393	1.30	4.225	1.28	4.537	1.21	4.379
July 31, a. m.		Aug. 10, a. m.		Aug. 19, a. m.		Aug. 26, a. m.		Sept. 6, a. m.		Sept. 17, a. m.		Sept. 28, a. m.	
4.95	3.014	4.57	3.209	4.92	3.008	5.03	3.138	4.94	2.759	4.96	3.287	4.88	3.243
4.18	3.211	3.89	3.399	4.12	3.213	4.48	3.367	4.29	2.997	4.25	3.434	4.17	3.458
3.48	3.425	3.24	3.602	3.42	3.385	3.45	3.550	3.48	3.190	3.47	3.617	3.47	3.674
2.84	3.624	2.67	3.772	2.76	3.632	2.80	3.727	2.78	3.450	2.73	3.881	2.72	3.895
2.05	3.891	2.06	4.025	2.05	3.909	2.07	4.055	2.07	3.776	2.02	4.189	2.05	4.162
1.40	4.174	1.29	4.329	1.25	4.192	1.23	4.365	1.28	4.212	1.27	4.521	1.24	4.497
Aug. 1, a. m.		Aug. 11, a. m.		Aug. 20, a. m.		Aug. 27, a. m.		Sept. 7, a. m.		Sept. 18, a. m.		Sept. 29, a. m.	
4.91	3.131	3.71	3.495	4.94	3.080	4.95	3.002	4.97	3.023	4.97	3.038	4.99	3.073
4.14	3.330	3.08	3.686	4.13	3.250	4.14	3.396	4.13	3.262	4.25	3.291	4.19	3.317
3.42	3.524	2.50	3.920	3.42	3.503	3.41	3.622	3.44	3.470	3.47	3.522	3.47	3.526
2.82	3.698	1.92	4.142	2.77	3.686	2.77	3.805	2.77	3.687	2.73	3.750	2.72	3.846
2.08	3.995	1.32	4.385	2.03	3.982	2.03	4.095	2.03	3.983	2.05	4.108	2.04	4.152
1.35	4.256			1.35	4.336	1.23	4.412	1.26	4.264	1.25	4.434	1.22	4.521
Aug. 3, a. m.		Aug. 12, a. m.		Aug. 21, a. m.		Aug. 28, a. m.		Sept. 8, a. m.		Sept. 19, a. m.		Sept. 30, a. m.	
5.06	3.138	4.97	3.265	4.97	3.317	4.96	3.042	5.02	3.270	4.98	3.221	4.91	3.180
4.17	3.327	4.16	3.477	4.15	3.520	4.13	3.222	4.13	3.410	4.25	3.427	4.19	3.352
3.48	3.538	3.46	3.635	3.39	3.756	3.41	3.381	3.39	3.617	3.47	3.676	3.47	3.575
2.83	3.763	2.80	3.862	2.80	3.948	2.90	3.646	2.77	3.797	2.79	3.866	2.72	3.825
2.11	4.035	2.00	4.140	2.05	4.230	2.03	3.904	2.02	4.046	2.05	4.154	2.04	4.100
1.40	4.317	1.32	4.446	1.30	4.502	1.31	4.177	1.32	4.331	1.25	4.452	1.26	4.509

[1] To reduce readings of Pyrheliometer S. I. 30 to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.3605.

TABLE 27.—*Pyrheliometer readings, Calama, Chile, 1918*—Continued.

M.	R.
Oct. 1, a. m.	
4.96	3.138
4.23	3.310
3.49	3.558
2.69	3.884
1.96	4.214
1.27	4.496
Oct. 2, a. m.	
4.80	3.013
4.11	3.210
3.42	3.474
2.72	3.717
2.05	4.007
1.26	4.338
Oct. 3, a. m.	
4.91	3.148
4.19	3.367
3.47	3.600
2.81	3.831
2.03	4.114
1.25	4.477
Oct. 4, a. m.	
4.88	3.078
4.17	3.306
3.46	3.556
2.71	3.765
2.00	4.111
1.23	4.446
Oct. 5, a. m.	
4.84	3.255
4.14	3.375
3.44	3.630
2.73	3.847
1.94	4.235
1.25	4.546
Oct. 6, a. m.	
4.83	3.223
4.13	3.431
3.43	3.672
2.72	3.898
1.97	4.214
1.24	4.498
Oct. 7, a. m.	
4.82	3.268
4.13	3.467
3.42	3.618
2.72	3.890
2.02	4.172
1.26	4.436
Oct. 8, a. m.	
4.56	3.173
3.92	3.378
3.29	3.563

M.	R.
Oct. 8, a. m.	
2.71	3.808
2.01	4.082
1.25	4.475
Oct. 9, a. m.	
4.88	3.125
4.17	3.337
3.46	3.565
2.74	3.819
2.01	4.116
1.25	4.482
Oct. 10, a. m.	
4.69	3.246
4.03	3.446
3.36	3.664
2.71	3.873
2.04	4.134
1.26	4.477
Oct. 11, a. m.	
4.60	3.018
3.96	3.213
3.32	3.426
2.70	3.613
1.88	3.999
1.22	4.315
Oct. 13, p. m.	
5.01	2.930
4.26	3.160
3.52	3.399
2.78	3.658
2.13	3.908
1.31	4.247
Oct. 14, p. m.	
5.18	3.008
4.39	3.173
3.70	3.317
2.83	3.630
2.17	3.898
1.40	4.280
Oct. 15, a. m.	
4.97	2.993
4.23	3.161
3.50	3.338
2.74	3.639
2.00	3.993
1.27	4.305
Oct. 16, a. m.	
4.87	2.732
4.16	3.004
3.45	3.322
2.71	3.628
1.95	3.968
1.28	4.191

M.	R.
Oct. 17, a. m.	
4.67	2.924
4.16	3.107
3.46	3.381
2.71	3.666
2.00	3.991
1.29	4.278
Oct. 18, a. m.	
4.85	3.197
4.15	3.354
3.46	3.545
2.74	3.802
1.96	4.214
1.24	4.552
Oct. 19, a. m.	
4.96	3.145
4.23	3.314
3.50	3.551
2.73	3.802
1.97	4.142
1.28	4.469
Oct. 21, a. m.	
4.86	3.173
4.17	3.367
3.46	3.588
2.74	3.809
1.96	4.094
1.24	4 419
Oct. 25, p. m.	
4.41	3.077
3.77	3 242
2.91	3.534
2.25	3.802
1.64	4.101
Oct. 28, a. m.	
4.51	3.112
3.85	3.304
3.24	3.524
2.68	3.706
1.96	4.022
1.27	4.321
Oct. 29, a. m.	
4.77	3.060
4.09	3.237
3.41	3.473
2.71	3.695
2.03	3.999
1.23	4.363
Oct. 30, a. m.	
4.77	2.961
4.10	3.150
3.42	3.453

M.	R.
Oct. 30, a. m.	
2.71	3.739
1.94	4.036
1.27	4.376
Oct. 31 a. m.	
4.88	3.019
3.92	3.270
3.22	3.474
2.62	3.696
1.91	3.973
1.24	4.088
Nov. 1, a. m.	
4.81	3.208
4.12	3.444
3.34	3.691
2.74	3.842
1.96	4.108
1.24	4.380
Nov. 5, p. m.	
4.74	3.113
4.08	3.301
3.45	3.439
2.77	3.721
2.08	3.981
1.27	4.416
Nov. 6, a. m.	
4.92	3.044
4.21	3.205
3.50	3.466
2.75	3.751
1.94	4.017
1.26	4.416
Nov. 7, a. m.	
4.83	3.232
4.16	3.424
3.46	3.650
2.78	3.898
1.98	4.196
1.41	4.423
Nov. 8, a. m.	
4.87	3.069
4.17	3.286
3.47	3.538
2.72	3.811
1.97	4.130
1.27	4.478
Nov. 9, a. m.	
4.99	2.879
4.27	3.170
3.63	3.340

M.	R.
Nov. 9, a. m.	
3.09	3.503
2.57	3.779
1.95	4.046
Nov. 12, p. m.	
4.83	3.240
4.15	3.401
3.46	3.659
2.75	3.904
2.10	4.142
1.31	4.479
Nov. 13, a. m.	
4.81	3.105
4.13	3.272
3.44	3.458
2.72	3.768
2.00	4.112
1.25	4.449
Nov. 15, p. m.	
4.84	2.882
4.10	3.071
3.42	3.305
2.73	3.603
1.99	3.928
1.26	4.313
Nov. 16, a. m.	
4.93	2.985
4.22	3.194
3.47	3.443
2.76	3.704
2.02	3.936
1.25	4.300
Nov. 17, a. m.	
4.89	2.953
4.20	3.148
3.50	3.400
2.75	3.635
2.01	3.955
1.26	4.388
Nov. 18, a. m.	
4.79	3.034
4.13	3.225
3.45	3.444
2.72	3.708
1.99	4.018
1.30	4.372
Nov. 19, a. m.	
4.84	2.771
4.16	2.975
3.48	3.206
2.74	3.493

M.	R.
Nov. 19, a. m.	
2.10	3.791
1.24	4.262
Nov. 20, a. m.	
4.82	2.259
4.15	2.500
3.46	2.790
2.73	3.137
2.01	3.536
1.30	3.988
Nov. 21, p. m.	
4.90	2.837
4.21	3.032
3.51	3.161
2.76	3.438
1.98	3.837
1.29	4.231
Nov. 22, p. m.	
4.88	2.941
4.19	3.125
3.49	3.374
2.73	3.670
1.97	3.999
1.27	4.368
Nov. 23, p. m.	
4.84	2.858
4.17	3.078
3.47	3.267
2.72	3.582
1.95	3.978
1.27	4.373
Nov. 25, a. m.	
4.85	2.648
4.17	2.870
3.48	3.133
2.72	3.458
2.02	3.811
1.26	4.224
Nov. 26, a. m.	
4.74	2.729
4.09	2.900
3.01	3.282
2.42	3.549
1.84	3.829
1.22	4.081
Nov. 27, p. m.	
4.82	3.040
4.15	3.242
3.47	3.465
2.74	3.722
2.00	4.002
1.31	4.380

M.	R.
Nov. 28, p. m.	
2.50	3.829
2.04	4.007
1.56	4.266
1.03	4.452
Nov. 29, p. m.	
4.86	3.205
4.12	3.360
3.49	3.540
2.76	3.805
2.00	4.116
1.28	4.404
Nov. 30, a. m.	
4.82	3.131
4.15	3.333
3.49	3.520
2.75	3.754
2.03	4.075
1.25	4.408
Dec. 1, a. m.	
4.82	3.117
4.14	3.315
3.47	3.538
2.75	3.801
2.04	4.115
1.26	4.467
Dec. 2, a. m.	
4.91	3.153
4.23	3.320
3.53	3.559
2.75	3.839
1.99	4.133
1.24	4.503
Dec. 3, a. m.	
4.89	3.212
4.21	3.399
3.61	3.602
2.98	3.812
2.34	4.055
1.75	4.307
Dec. 4, a. m.	
4.87	3.332
4.20	3.472
3.51	3.644
2.72	3.981
Dec. 5, p. m.	
4.85	2.735
4.17	2.965
3.49	3.304
2.73	3.740
1.97	4.123
1.27	4.496

TABLE 27.—*Pyrheliometer readings, Calama, Chile, 1918*—Continued.

M.	R.	M.	R.	M.	R.	M.	R.	M.	R.	M.	R.	M.	R.
Dec. 6, p. m.		Dec. 8, a. m.		Dec. 10, a. m.		Dec. 12, a. m.		Dec. 22, a. m.		Dec. 26, a. m.		Dec. 28, a. m.	
4.81	2.925	4.87	2.623	4.98	2.875	5.00	3.064	5.00	2.805	4.94	2.827	4.89	3.120
4.15	2.956	4.19	2.836	4.28	3.076	4.30	3.199	4.29	3.001	4.25	3.010	3.72	3.472
3.43	3.236	3.50	3.069	3.56	3.324	3.44	3.522	3.58	3.229	3.55	3.223	3.09	3.680
2.73	3.560	2.77	3.378	2.81	3.598	2.73	3.803	2.73	3.533	2.72	3.574	2.54	3.877
1.97	3.982	2.03	3.735	2.01	3.970	1.88	4.194	2.14	3.820	2.01	3.895	1.93	4.150
1.24	4.507	1.29	4.134	1.24	4.406	1.28	4.495	1.23	4.325	1.23	4.365	1.30	4.500
Dec. 7, a. m.		Dec. 9, p. m.		Dec. 11, a. m.		Dec. 13, p. m.		Dec. 23, a. m.		Dec. 27, a. m.		Dec. 31, a. m.	
4.86	2.883	4.79	2.761	4.91	3.102	4.75	2.910	4.92	2.969	4.79	3.051	4.20	3.175
4.18	3.083	4.14	2.953	4.23	3.279	4.12	3.086	4.24	3.170	4.14	3.238	3.70	3.340
3.50	3.333	3.42	3.236	3.53	3.502	3.46	3.354	3.49	3.440	3.48	3.477	3.01	3.585
2.71	3.661	2.77	3.513	2.76	3.791	2.77	3.664	2.74	3.732	2.75	3.798	2.42	3.813
2.04	3.951	1.96	3.879	2.03	4.082	2.04	4.023	2.10	3.980	2.09	4.043	1.82	4.071
1.27	4.386	1.31	4.227	1.25	4.448	1.26	4.445	1.32	4.408	1.26	4.463	1.23	4.404

TABLE 28.—*Pyrheliometer readings, Calama, Chile, 1919.*

[Pyrheliometer S. I. 30.[1]—Observers A. F. M. and L. H. A.]

M.	R.
Jan. 1, a. m.	
4.88	2.949
4.21	3.140
3.52	3.389
2.75	3.709
2.07	4.013
1.26	4.404
Jan. 2, a. m.	
4.91	3.021
4.23	3.195
3.53	3.421
2.74	3.721
2.10	4.023
1.27	4.425
Jan. 3, a. m.	
4.83	2.946
4.18	3.133
3.49	3.369
2.73	3.691
2.09	3.976
Jan. 6, a. m.	
4.90	2.675
4.21	2.875
3.51	3.101
2.75	3.395
2.09	3.676
1.36	4.055
Jan. 8, a. m.	
4.93	2.797
4.24	2.979
3.54	3.200

M.	R.
Jan. 8, a. m.	
2.74	3.506
2.08	3.796
1.34	4.214
Jan. 11, a. m.	
4.91	3.066
4.23	3.214
3.53	3.410
2.75	3.695
2.11	3.983
1.32	4.380
Jan. 12, a. m.	
4.91	3.279
4.22	3.428
3.53	3.642
2.65	3.908
2.05	4.133
1.30	4.569
Jan. 14, a. m.	
3.34	3.690
2.95	3.860
2.38	4.150
1.87	4.301
1.23	4.690
Jan. 16, a. m.	
4.15	3.006
3.65	3.192
3.11	3.390
2.59	3.599
2.01	3.882
1.33	4.281

M.	R.
Jan. 17, p. m.	
5.08	2.966
4.35	3.167
3.60	3.301
2.80	3.601
2.16	3.892
1.27	4.372
Jan. 18, a. m.	
4.89	3.174
4.21	3.324
3.51	3.524
2.74	3.819
2.11	4.078
1.27	4.505
Jan. 19, a. m.	
4.93	3.350
4.23	3.536
3.53	3.712
2.75	3.980
2.12	4.241
1.33	4.605
Jan. 20, a. m.	
4.79	3.069
4.13	3.301
3.46	3.504
2.73	3.765
2.12	3.996
1.31	4.433
Jan. 21, a. m.	
4.93	3.027
4.23	3.195
3.53	3.376

M.	R.
Jan. 21, a. m.	
2.67	3.705
2.09	3.938
1.30	4.348
Jan. 22, a. m.	
4.88	2.915
4.20	3.104
3.50	3.322
2.72	3.612
2.10	3.907
1.31	4.297
Jan. 23, a. m.	
4.92	2.787
4.22	3.019
3.52	3.264
2.73	3.532
2.09	3.844
1.38	4.232
Jan. 24, a. m.	
4.84	2.692
4.18	2.903
3.49	3.135
2.66	3.462
2.10	3.693
1.37	4.074
Jan. 25, a. m.	
4.79	2.595
4.13	2.801
3.44	3.022
2.73	3.376
2.12	3.682
1.41	4.091

M.	R.
Jan. 29, a. m.	
4.87	2.990
4.17	3.177
3.48	3.395
2.77	3.653
1.94	3.971
1.29	4.361
Feb. 3, p. m.	
5.11	2.944
4.35	3.138
3.70	3.344
2.24	3.858
1.56	4.214
Feb. 6, a. m.	
4.35	3.027
3.79	3.187
3.24	3.378
2.69	3.578
2.08	3.877
1.49	4.152
Feb. 7, a. m.	
4.38	3.165
3.81	3.330
3.26	3.548
2.67	3.738
2.08	3.988
1.47	4.297
Feb. 8, a. m.	
4.47	3.209
3.87	3.395
3.30	3.567

M.	R.
Feb. 8, a. m.	
2.71	3.830
2.10	4.088
1.45	4.400
Feb. 9, a. m.	
4.49	3.063
3.89	3.283
3.31	3.499
2.70	3.741
2.10	3.998
1.37	4.329
Feb. 10, a. m.	
4.51	2.977
3.90	3.168
3.33	3.367
2.72	3.599
2.11	3.853
1.45	4.102
Feb. 11 'a. m.	
4.50	3.131
3.91	3.317
3.33	3.463
2.69	3.730
2.09	3.954
1.40	4.247
Feb. 12, a. m.	
4.49	2.928
3.89	3.115
3.31	3.302
2.71	3.567
2.10	3.870
1.45	4.200

M.	R.
Feb. 13, a. m.	
4.55	2.780
3.92	2.968
3.34	3.195
2.70	3.470
2.11	3.739
1.46	4.130
Feb. 14, a. m.	
4.53	2.786
3.92	2.996
3.33	3.251
2.72	3.505
2.11	3.777
1.44	4.156
Feb. 15, a. m.	
4.22	2.642
3.69	2.847
3.13	3.082
2.58	3.337
2.07	3.574
1.40	3.875
Feb. 16, a. m.	
4.62	2.664
3.98	2.860
3.38	3.112
2.72	3.401
2.11	3.656
1.47	4.052
Feb. 17, a. m.	
4.61	2.992
3.97	3.171
3.37	3.392

[1] To reduce readings of Pyrheliometer S. I. 30 to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.3605.

TABLE 28.—*Pyrheliometer readings, Calama, Chile, 1919*—Continued.

M.	R.
Feb. 17, a. m.	
2.72	3.639
2.10	3.927
1.46	4.240
Feb. 18, a. m.	
4.56	3.124
3.93	3.310
3.34	3.503
2.70	3.703
2.09	3.965
1.43	4.365
Feb. 19, a. m.	
4.60	3.181
3.97	3.365
3.36	3.579
2.71	3.812
2.10	4.068
1.46	4.347
Feb. 22, a. m.	
4.39	3.214
3.75	3.417
2.95	3.697
2.43	3.865
1.91	4.097
1.30	4.362
Feb. 24, p. m.	
4.88	2.929
4.17	3.115
3.20	3.471
2.47	3.766
1.81	4.062
1.28	4.316
Feb. 25, a. m.	
4.39	3.182
3.77	3.364
2.93	3.631
2.43	3.802
1.93	4.042
1.28	4.358
Feb. 26, a. m.	
4.57	3.067
3.95	3.252
3.08	3.533
2.48	3.739
1.92	3.976
Feb. 27, p. m.	
4.66	2.693
4.01	2.903
3.34	3.092
1.52	3.868

M.	R.
Mar. 1, a. m.	
3.48	2.679
2.93	2.934
2.42	3.196
1.91	3.477
1.38	3.902
Mar. 3, p. m.	
5.23	2.805
4.43	2.996
3.78	3.197
3.23	3.364
2.24	3.784
1.52	4.119
Mar. 5, p. m.	
5.16	2.724
4.39	2.940
3.76	3.138
3.12	3.417
2.56	3.680
2.01	3.957
Mar. 6, p. m.	
4.80	3.051
4.12	3.231
3.47	3.441
2.77	3.683
2.15	3.913
1.54	4.170
Mar. 9, a. m.	
4.46	2.773
3.86	2.953
3.29	3.173
2.64	3.375
Mar. 10, a. m.	
3.88	3.216
3.41	3.310
2.93	3.454
2.43	3.658
1.92	3.857
1.44	4.130
Mar. 13, p. m.	
4.98	2.803
4.27	3.042
3.61	3.218
3.04	3.430
1.48	4.194
Mar. 17, a. m.	
4.62	2.708
3.98	2.935
3.37	3.136
2.72	3.354
2.11	3.602
1.46	4.036

M.	R.
Mar. 18, a. m.	
4.56	2.974
3.93	3.120
3.34	3.410
2.70	3.667
2.10	3.887
1.46	4.250
Mar. 19, a. m.	
4.55	2.929
3.93	3.137
3.34	3.335
2.72	3.585
2.10	3.831
1.52	4.118
Mar. 21, a. m.	
4.58	2.848
3.95	3.037
3.35	3.225
2.73	3.433
2.12	3.710
1.59	3.961
Mar. 25, a. m.	
4.95	2.814
3.91	3.086
3.32	3.301
2.74	3.486
2.09	3.783
1.56	4.043
Mar. 26, a. m.	
4.61	3.153
3.97	3.347
3.38	3.558
2.72	3.750
2.15	3.980
1.58	4.240
Mar. 28, a. m.	
4.62	3.076
3.98	3.255
3.43	3.433
2.79	3.649
2.12	3.940
1.59	4.199
Mar. 30, a. m.	
4.58	2.695
3.95	2.893
3.35	3.117
2.75	3.367
2.12	3.639
Mar. 31, a. m.	
4.66	2.707
4.01	2.916
3.40	3.110

M.	R.
Mar. 31, a. m.	
2.75	3.337
2.12	3.648
1.62	3.898
Apr. 1, a. m.	
4.66	2.778
4.01	2.983
3.41	3.199
2.72	3.474
2.11	3.737
1.62	3.979
Apr. 2, a. m.	
4.58	2.939
3.95	3.112
3.36	3.324
2.72	3.564
2.11	3.809
1.62	4.064
Apr. 3, a. m.	
4.59	2.697
3.96	2.899
3.37	3.111
2.73	3.374
2.12	3.636
1.63	3.908
Apr. 4, a. m.	
4.58	2.520
3.96	2.725
3.37	2.957
2.76	3.216
2.12	3.532
1.63	3.857
Apr. 5, a. m.	
4.59	2.876
3.97	3.057
3.38	3.232
2.76	3.461
2.13	3.728
1.63	4.010
Apr. 6, a. m.	
4.61	2.878
3.99	3.088
3.39	3.262
2.74	3.496
2.12	3.791
1.63	4.058
Apr. 7, a. m.	
4.53	2.990
3.93	3.164
3.35	3.344
2.75	3.581
2.12	3.815
1.63	4.113

M.	R.
Apr. 8, a. m.	
4.54	3.056
3.93	3.218
3.35	3.414
2.75	3.650
2.12	3.897
1.63	4.122
Apr. 9, a. m.	
4.48	3.197
3.89	3.304
3.32	3.539
2.75	3.756
2.14	3.969
1.63	4.211
Apr. 10, a. m.	
4.55	3.251
3.95	3.396
3.37	3.581
2.76	3.775
2.15	3.979
1.65	4.164
Apr. 11, a. m.	
4.48	3.224
3.89	3.374
3.33	3.556
2.74	3.750
2.16	3.954
1.67	4.180
Apr. 12, a. m.	
4.53	3.025
3.93	3.163
3.36	3.348
2.79	3.553
2.24	3.720
1.72	3.963
Apr. 13, a. m.	
4.51	3.008
3.92	3.200
3.35	3.378
2.75	3.574
2.22	3.802
1.70	3.974
Apr. 14, a. m.	
4.57	3.020
3.97	3.160
3.38	3.357
2.75	3.603
2.23	3.811
1.72	4.050
Apr. 15, a. m.	
4.56	3.110
3.95	3.267
3.38	3.451

M.	R.
Apr. 15, a. m.	
2.80	3.663
2.24	3.879
1.73	4.152
Apr. 16, a. m.	
4.54	3.141
3.45	3.436
2.80	3.665
Apr. 18, a. m.	
4.50	2.934
3.92	3.117
3.35	3.330
2.73	3.571
2.22	3.790
1.72	4.027
Apr. 19, a. m.	
4.11	3.081
3.62	3.227
3.13	3.404
2.66	3.586
2.14	3.795
1.63	3.981
Apr. 22, a. m.	
4.47	2.914
3.90	3.101
3.34	3.298
2.74	3.466
2.01	3.817
Apr. 23, p. m.	
4.61	3.231
4.00	3.388
3.41	3.525
2.83	3.692
2.32	3.875
1.83	4.062
Apr. 24, a. m.	
4.42	3.286
3.86	3.442
3.32	3.588
2.73	3.765
2.20	3.955
1.72	4.176
Apr. 25, a. m.	
4.30	3.256
3.78	3.410
3.22	3.594
2.69	3.774
2.14	3.972
1.65	4.180
Apr. 26, a. m.	
4.54	3.143
3.96	3.304
3.39	3.474

M.	R.
Apr. 26, a. m.	
2.77	3.670
2.19	3.926
1.71	4.101
Apr. 27, a. m.	
4.49	3.164
3.91	3.340
3.36	3.504
2.78	3.715
2.23	3.910
1.74	4.133
Apr. 28, a. m	
4.51	3.241
3.93	3.375
3.38	3.548
2.76	3.790
2.25	3.969
1.74	4.194
Apr. 29, a. m.	
4.51	3.216
3.94	3.349
3.38	3.513
2.80	3.700
2.24	3.923
1.73	4.131
Apr. 30, a. m.	
4.53	3.188
3.96	3.324
3.39	3.498
2.81	3.695
2.25	3.898
1.75	4.112
May 1, a. m.	
4.48	3.319
3.91	3.470
3.37	3.601
2.80	3.798
2.24	4.006
1.75	4.197
May 2, a. m.	
4.50	3.262
3.93	3.376
3.38	3.551
2.80	3.744
2.25	3.944
1.74	4.177
May 3, a. m.	
4.51	3.273
3.94	3.394
3.38	3.533
2.81	3.710
2.26	3.890
1.76	4.175

TABLE 28.—*Pyrheliometer readings, Calama, Chile, 1919*—Continued.

M.	R.
May 4, a. m.	
4.54	3.315
3.97	3.451
3.40	3.622
2.80	3.815
2.24	4.030
1.74	4.221
May 5, a. m.	
4.48	3.334
3.92	3.483
3.37	3.658
2.80	3.855
2.25	4.050
1.75	4.222
May 6, a. m.	
4.49	3.214
3.74	3.423
3.24	3.592
2.66	3.804
2.12	3.994
1.64	4.181
May 7, a. m.	
4.51	3.250
3.95	3.394
3.40	3.560
2.82	3.744
2.27	3.931
1.68	4.178
May 8, a. m.	
4.53	3.177
3.96	3.273
3.41	3.533
2.83	3.703
2.29	3.908
1.77	4.121
May 9, a. m.	
4.55	3.220
3.98	3.347
3.42	3.528
2.79	3.724
2.28	3.888
1.73	4.083
May 10, a. m.	
5.05	3.002
4.35	3.168
3.84	3.316
3.32	3.478
2.75	3.653
2.05	3.914
May 11, a. m.	
4.51	2.946
3.96	3.119
3.41	3.306

M.	R.
May 11, a. m.	
2.81	3.532
2.28	3.744
1.76	3.951
May 12, a. m.	
4.53	2.966
3.97	3.097
3.42	3.290
2.82	3.489
2.29	3.685
1.76	3.920
May 13, a. m.	
4.48	2.940
3.94	3.074
3.40	3.238
2.42	3.581
May 14, a. m.	
4.50	2.822
3.94	3.006
3.41	3.190
2.86	3.360
May 15, a. m.	
4.51	3.051
3.95	3.194
3.41	3.347
2.82	3.522
2.29	3.703
May 16, a. m.	
4.31	3.222
3.81	3.358
3.14	3.542
2.64	3.666
2.08	3.852
1.58	4.118
May 18, p. m.	
4.40	3.178
3.89	3.284
3.18	3.494
2.63	3.669
2.17	3.818
1.68	3.953
May 19, a. m.	
4.59	3.189
4.02	3.301
3.31	3.495
2.78	3.669
2.31	3.828
1.82	3.987
May 20, a. m.	
5.11	3.030
4.43	3.221
3.78	3.397

M.	R.
May 20, a. m.	
3.12	3.580
2.48	3.793
1.85	4.015
May 21, a. m.	
4.56	3.191
3.95	3.367
3.40	3.503
2.62	3.784
2.07	3.969
1.55	4.172
May 22, a. m.	
4.48	3.246
3.89	3.420
3.36	3.561
2.78	3.736
2.07	3.953
May 23, a. m.	
4.54	3.151
3.98	3.280
3.43	3.479
2.85	3.669
2.13	3.933
1.61	4.178
May 24, a. m.	
4.63	3.148
4.06	3.286
3.51	3.457
2.89	3.632
2.20	3.845
1.67	4.080
May 28, a. m.	
4.74	3.216
4.08	3.440
3.52	3.605
2.89	3.787
2.17	4.002
1.64	4.264
May 29, p. m.	
4.69	3.276
4.12	3.372
3.35	3.599
2.77	3.771
2.21	3.953
1.72	4.146
May 30, a. m.	
4.66	3.236
4.05	3.421
3.49	3.552
2.90	3.777
2.23	4.027
1.67	4.234

M.	R.
May 31, a. m.	
4.56	3.252
4.03	3.432
3.44	3.602
2.86	3.763
2.14	4.022
1.61	4 244
June 1, a. m.	
4.76	3.200
4.16	3.379
3.55	3.565
2.98	3.782
2.27	3.950
1.75	4.114
June 2, p. m.	
4.57	3.170
4.03	3.296
3.45	3.449
2.85	3.551
2.33	3.782
1.77	4.007
June 3, p. m.	
1.76	4.142
2.37	3.911
2.90	3.734
3.33	3.563
4.16	3.387
4.72	3.221
June 4, a. m.	
4.65	3.324
4.09	3.484
3.51	3.627
2.87	3.820
2.17	4.100
1.66	4.235
June 5, a. m.	
4.75	3.260
4.16	3.407
3.59	3.551
2.97	3.739
2.25	3.976
1.67	4.217
June 9, a. m.	
4.64	3.115
4.08	3.225
3.54	3.393
2.94	3.586
2.27	3.815
1.76	4.021
June 10, a. m.	
4.71	2.903
4.13	3.051

M.	R.
June 10, a. m.	
3.57	3.328
2.97	3.548
2.24	3.832
1.79	3.988
June 14, a. m.	
4.57	2.850
3.58	3.227
3.04	3.359
2.49	3.567
1.87	3.837
June 15, a. m.	
4.72	2.877
4.10	3.044
3.53	3.179
2.89	3.388
2.30	3.593
1.89	3.800
June 16, a. m.	
4.68	3.000
4.14	3.120
3.55	3.301
3.00	3.483
2.35	3.671
1.89	3.850
June 19, p. m.	
5.12	3.004
4.44	3.149
3.83	3.309
3.28	3.464
2.62	3.651
1.88	4.027
June 20, a. m.	
3.91	3.400
3.48	3.532
3.05	3.680
2.50	3.869
1.93	4.044
June 21, a. m.	
4 84	3.128
4.24	3.298
3.70	3.450
3.12	3.597
2.43	3.911
1.92	4.123
June 22, a. m.	
4.99	3.123
4.34	3.260
3.78	3.417
3.24	3.582
2.47	3.861
1.98	4.028

M.	R.
June 23, a. m.	
4.97	3.192
4.36	3.360
3.77	3.479
3.23	3.667
2.47	3.979
1.98	4.095
June 24, a. m.	
4.89	3.161
4.29	3.341
3.74	3.504
3.22	3.662
2.52	3.881
1.99	4.074
June 25, a. m.	
1.98	4.050
June 26, a. m.	
2.00	4.023
June 27, a. m.	
4.70	3.102
4.15	3.299
3.63	3.404
3.10	3.560
2.49	3.831
2.01	4.004
June 28, p. m.	
2.00	3.976
June 29, a. m.	
2.01	3.868
June 30, a. m.	
2.00	3.886
July 1, a. m.	
4.81	3.007
4.22	3.223
3.52	3.404
2.97	3.559
2.48	3.739
1.99	3.917
July 2, a. m.	
1.99	3.868
July 3, a. m.	
4.98	3.042
3.36	3.177
3.60	3.352
2.98	3.547
2.49	3.707
1.99	3.846

M.	R.
July 4, a. m.	
2.85	3.538
July 6, a. m.	
1.98	3.865
July 9, a. m.	
1.99	3.928
July 10, a. m.	
2.00	3.917
July 11, a. m.	
3.00	3.522
1.99	3.897
July 12, a. m.	
4.65	3.073
4.09	3.209
3.53	3.370
2.97	3.543
2.49	3.731
1.98	3.890
July 13, a. m.	
2.99	3.585
2.00	3.924
July 14, a. m.	
2.98	3.567
July 15, a. m.	
2.95	3.666
1.99	4.021
July 17, a. m.	
5.05	2.797
4.38	2.950
3.70	3.317
3.02	3.486
2.48	3.800
2.00	4.038
July 18, a. m.	
4.95	3.013
4.30	3.196
3.68	3.353
2.98	3.568
2.45	3.747
1.98	3.919
July 19, a. m.	
2.96	3.512
1.99	3.890
July 20, a. m.	
2.97	3.491
1.99	3.866

TABLE 28.—*Pyrheliometer readings, Calama, Chile, 1919*—Continued.

M.	R.
July 21, a. m.	
4.98	2.959
4.32	3.119
3.68	3.302
2.98	3.525
2.49	3.687
1.98	3.910
July 22, a. m.	
2.99	3.433
1.99	3.795
July 23, a. m.	
2.97	3.608
2.46	3.817
1.98	4.018
July 24, a. m.	
4.91	3.143
4.28	3.289
3.65	3.451
2.98	3.605
2.48	3.819
1.99	4.018
July 25, a. m.	
2.98	3.692
1.98	4.080
July 26, a. m.	
2.98	3.493
1.97	4.000
July 27, a. m.	
2.97	3.503
1.99	3.931
July 28, a. m.	
4.91	3.061
4.26	3.211
3.63	3.410
2.99	3.597
2.47	3.756
1.99	3.948
July 29, a. m.	
1.58	4.028
July 30, a. m.	
2.98	3.468
1.96	3.828
July 31, a. m.	
2.97	3.499
1.93	3.960
Aug. 1, a. m.	
4.85	3.158
4.20	3.301
3.59	3.462
2.98	3.651
2.48	3.819
1.98	4.027
Aug. 2, a. m.	
2.98	3.510
1.97	3.898
Aug. 3, a. m.	
3.00	3.410
1.97	3.848
Aug. 4, a. m.	
2.98	3.542
1.94	3.938
Aug. 5, a. m.	
4.75	3.007
4.13	3.144
3.54	3.332
2.97	3.556
2.48	3.712
1.97	3.893
Aug. 6, a. m.	
2.94	3.421
1.95	3.824
Aug. 7, a. m.	
2.98	3.565
1.98	3.967
Aug. 8, a. m.	
4.86	3.069
4.21	3.256
3.59	3.436
2.98	3.641
2.46	3.839
1.89	4.028
Aug. 9, a. m.	
2.96	3.652
2.47	3.819
1.98	4.004
Aug. 10, a. m.	
2.98	3.628
1.98	3.968
Aug. 11, a. m.	
2.01	3.963
Aug. 13, a. m.	
4.86	2.843
4.20	3.021
3.50	3.240
2.96	3.436
2.48	3.647
1.98	3.867
Aug. 14, a. m.	
1.97	3.809
Aug. 15, a. m.	
2.93	3.640
1.96	3.948
Aug. 16, p. m.	
2.07	3.835
Aug. 17, a. m.	
2.96	3.443
1.96	3.890
Aug. 18, a. m.	
4.87	3.167
4.20	3.285
3.56	3.467
3.00	3.684
2.48	3.886
1.98	4.051
Aug. 19, a. m.	
2.55	3.611
1.98	3.834
Aug. 20, a. m.	
2.97	3.504
1.99	3.895
Aug. 21, a. m.	
2.96	3.509
1.98	3.837
Aug. 22, a. m.	
4.92	2.999
4.22	3.187
3.57	3.385
2.97	3.584
2.47	3.757
1.98	3.950
Aug. 23, a. m.	
2.96	3.620
1.99	4.030
Aug. 24, a. m.	
2.98	3.528
1.98	4.023
Aug. 25, a. m.	
2.93	3.631
1.98	4.043
Aug. 26, a. m.	
4.85	3.041
4.18	3.224
3.54	3.407
2.98	3.550
2.47	3.745
1.98	3.956
Aug. 27, a. m.	
2.98	3.638
1.97	4.048
Aug. 28, a. m.	
2.96	3.702
1.99	4.063
Aug. 29, a. m.	
4.93	3.090
4.23	3.329
3.57	3.517
2.99	3.729
2.48	3.901
1.99	4.095
Aug. 30, a. m.	
2.99	3.710
1.98	4.109
Aug. 31, a. m.	
2.99	3.682
1.99	4.093
Sept. 1, a. m.	
1.98	4.025
Sept. 2, a. m.	
2.98	3.574
1.98	3.987
Sept. 3, p. m.	
3.10	3.439
2.02	3.883
Sept. 4, a. m.	
4.90	2.968
4.19	3.154
3.50	3.384
2.97	3.562
2.46	3.718
1.98	3.926
Sept. 5, a. m.	
2.97	3.552
1.98	3.940
Sept. 6, a. m.	
2.96	3.631
1.97	4.026
Sept. 7, a. m.	
2.99	3.685
1.98	4.084
Sept. 8, a. m.	
2.95	3.631
1.98	4.044
Sept. 9, a. m.	
4.78	2.971
4.11	3.192
3.47	3.388
2.94	3.556
2.46	3.758
1.96	3.935
Sept. 10, a. m.	
2.93	3.537
1.98	3.949
Sept. 11 a. m.	
1.98	4.006
Sept. 12, a. m.	
4.78	3.170
4.10	3.345
3.46	3.507
2.97	3.638
2.45	3.813
1.96	3.997
Sept. 13, a. m.	
2.95	3.837
1.98	4.175
Sept. 14, a. m.	
2.95	3.681
1.97	4.032
Sept. 15, a. m.	
1.96	3.948
Sept. 17, a. m.	
4.78	2.762
4.11	2.974
3.47	3.125
2.94	3.352
2.44	3.533
1.97	3.763
Sept. 18, a. m.	
2.95	3.583
1.97	4.026
Sept. 19, a. m.	
2.95	3.752
1.97	4.144
Sept. 20, a. m.	
4.88	3.098
4.17	3.296
3.51	3.485
2.96	3.642
2.46	3.834
1.98	4.046
Sept. 21, a. m.	
1.88	4.132
Sept. 22, p. m.	
3.08	3.427
2.03	3.824
Sept. 23, a. m.	
4.88	2.735
4.17	2.968
3.51	3.205
2.96	3.426
2.46	3.608
1.99	3.844
Sept. 25, a. m.	
2.95	3.492
1.98	3.859
Sept. 26, a. m.	
4.89	3.152
4.17	3.361
3.51	3.542
2.96	3.730
2.46	3.921
1.98	4.137
Sept. 27, a. m.	
2.98	3.548
1.97	3.955
Sept. 28, a. m.	
2.98	3.621
1.98	4.108
Sept. 29, a. m.	
2.92	3.570
1.98	3.955
Sept. 30, a. m.	
2.19	3.845
1.97	3.898
Oct. 2, a. m.	
4.86	2.862
4.02	3.073
3.20	3.329
2.60	3.543
1.93	3.828
Oct. 7, a. m.	
4.83	2.690
4.14	2.849
3.48	3.067
2.94	3.271
2.48	3.451
1.98	3.680
Oct. 8, a. m.	
2.95	3.594
1.97	3.999
Oct. 9, a. m.	
2.97	3.569
1.98	3.976
Oct. 10, a. m.	
5.17	2.835
4.37	3.037
3.70	3.270
2.95	3.491
1.91	3.884
1.44	4.095
Oct. 11, a. m.	
2.90	3.425
1.98	3.827
Oct. 12, a. m.	
2.95	3.123
1.97	3.688
Oct. 13, a. m.	
2.72	3.503
1.96	3.881
Oct. 14, a. m.	
2.96	3.725
1.99	4.103
Oct. 15, a. m.	
5.16	3.030
4.37	3.243
3.70	3.529
2.97	3.745
1.98	4.136
1.42	4.377
Oct. 17, a. m.	
1.22	4.338
Oct. 19, a. m.	
2.95	3.587
1.98	4.023
Oct. 20, a. m.	
2.94	3.587
1.98	3.982

TABLE 28.—*Pyrheliometer readings, Calama, Chile, 1919*—Continued.

Date	M.	R.
Oct. 21, a. m.	5.07	2.915
	4.31	3.160
	3.66	3.388
	2.99	3.632
	1.99	4.025
	1.43	4.300
Oct. 23, a. m.	2.03	4.013
	1.02	4.424
Oct. 24, a. m.	5.13	2.612
	4.36	2.916
	3.70	3.081
	2.95	3.461
	1.98	3.955
	1.47	4.175
Oct. 25, a. m.	1.49	4.224
Oct. 26, a. m.	2.96	3.487
	1.97	3.917
Oct. 28, a. m.	1.30	4.388
Oct. 31, a. m.	1.31	4.371
Nov. 1, a. m.	2.82	3.777
	1.97	4.103
	1.49	4.385
Nov. 2, a. m.	1.44	4.441
Nov. 3, a. m.	1.15	4.520
Nov. 4, a. m.	1.48	4.410
Nov. 5, a. m.	5.13	2.968
	4.36	3.221
	3.70	3.498
	2.96	3.782
	1.98	4.172
	1.49	4.395
Nov. 6, p. m.	1.11	4.492
Nov. 7, a. m.	2.98	3.837
	1.97	4.219
Nov. 9, a. m.	1.02	4.587
Nov. 10, a. m.	4.90	3.078
	4.20	3.279
	3.60	3.499
	2.96	3.714
	1.98	4.079
	1.47	4.358
Nov. 11, a. m.	2.13	3.917
Nov. 12, a. m.	2.96	3.548
	1.97	3.994
	1.48	4.224
Nov. 13, a. m.	1.97	3.969
	1.36	4.259
Nov. 15, a. m.	2.97	3.451
	1.97	3.928
	1.48	4.198
Nov. 17, a. m.	5.03	3.032
	4.29	3.231
	3.66	3.404
	2.98	3.615
	1.97	4.038
	1.42	4.292
Nov. 18, a. m.	2.96	3.646
	1.99	4.065
	1.50	4.290
Nov. 21, a. m.	1.68	4.121
	1.50	4.220
Nov. 22, a. m.	1.63	4.121
	1.49	4.254
Nov. 23, a. m.	1.98	3.949
	1.50	4.217
Nov. 24, a. m.	1.98	3.938
Nov. 25, p. m.	1.13	4.432
Nov. 26, a. m.	1.52	4.310
Nov. 27, a. m.	4.80	2.734
	4.15	2.989
	3.56	3.186
	2.97	3.421
	1.99	3.886
	1.50	4.111
Nov. 28, a. m.	1.98	4.039
	1.50	4.293
Nov. 29, a. m.	1.98	4.110
	1.50	4.345
Nov. 30, a. m.	1.99	4.099
	1.40	4.420
Dec. 1, p. m.	2.03	4.051
	1.42	4.379
Dec. 3, p. m.	2.01	3.989
	1.51	4.274
	1.07	4.487
Dec. 5, a. m.	4.87	2.915
	4.19	3.114
	3.59	3.311
	2.95	3.566
	1.99	3.955
	1.50	4.220
Dec. 6, a. m.	1.97	3.632
	1.49	3.947
Dec. 7, a. m.	1.42	3.991
Dec. 8, a. m.	1.97	3.778
	1.50	4.100
Dec. 9, a. m.	1.36	4.352
Dec. 10, p. m.	2.01	3.815
	1.69	4.049
Dec. 12, a. m.	4.88	2.907
	4.21	3.097
	3.61	3.304
	2.95	3.513
	1.98	3.951
	1.43	4.227
Dec. 15, a. m.	1.68	3.704
	1.50	3.807
Dec. 16, a. m.	1.06	4.175
Dec. 17, a. m.	4.20	2.655
	3.65	2.867
	3.08	3.097
	2.51	3.388
	1.97	3.642
	1.35	3.976
Dec. 18, a. m.	1.98	3.773
	1.53	3.983
Dec. 19, p. m.	1.51	4.099
	1.14	4.278
Dec. 20, a. m.	1.11	4.333
Dec. 21, a. m.	1.25	4.278
Dec. 22, a. m.	4.91	2.522
	4.23	2.748
	3.62	2.976
	3.00	3.255
	1.98	3.738
	1.50	4.052
Dec. 23, a. m.	4.93	2.434
	4.25	2.670
	3.64	2.898
	2.98	3.205
	1.98	3.697
	1.50	4.005
Dec. 24, a. m.	4.97	2.781
	4.27	2.968
	3.66	3.154
	2.99	3.445
	1.99	3.852
	1.50	4.164
Dec. 25, a. m.	1.99	3.750
	1.49	4.018
Dec. 26, a. m.	5.01	2.151
	4.30	2.447
	3.67	2.660
	2.97	3.002
	1.98	3.529
	1.49	3.868
Dec. 27, a. m.	4.94	2.198
	4.26	2.359
	3.65	2.585
	2.98	2.841
	1.99	3.323
Dec. 28, a. m.	1.98	3.675
	1.50	3.965
Dec. 29, a. m.	1.12	4.196
Dec. 31, a. m.	4.91	2.518
	4.23	2.713
	2.51	3.337
	2.03	3.622
	1.56	3.904

Table 29.—*Pyrheliometer readings, Calama, Chile, 1920.*

[Pyrheliometer S. I. 30[1]—Observers A. F. M., L. H. A. and P. G.]

Date	M.	R.
Jan. 2, a. m.	4.80	2.998
	4.15	3.206
	3.56	3.414
	2.96	3.622
	1.97	4.023
	1.49	4.291
Jan. 3, a. m.	1.98	3.963
	1.49	4.207
Jan. 4, a. m.	1.97	4.014
	1.49	4.280
Jan. 5, a. m.	1.37	4.315
Jan. 7, p. m.	2.15	3.653
Jan. 10, a. m.	1.97	3.776
Jan. 11, a. m.	1.38	3.956
Jan. 12, a. m.	1.02	4.203
	1.01	4.213
Jan. 14, a. m.	1.00	4.426
Jan. 15, a. m.	1.98	3.630
	1.50	3.967
Jan. 16, a. m.	1.98	3.422
	1.49	3.678
Jan. 17, a. m.	1.98	3.620
	1.49	3.909
Jan. 18, a. m.	1.99	3.617
	1.49	3.946
Jan. 19, a. m.	4.85	2.580
	4.17	2.789
	3.58	2.987
	2.96	3.236
	1.98	3.713
	1.50	3.994
Jan. 20, a. m.	1.98	3.457
	1.50	3.807
Jan. 21, a. m.	1.99	3.496
	1.39	3.766
Jan. 22, a. m.	1.13	4.186
Jan. 23, a. m.	1.98	3.784
	1.55	4.036
Jan. 24, a. m.	1.97	3.721
	1.49	4.007
Jan. 25, a. m.	4.93	2.652
	4.24	2.873
	3.61	3.090
	2.95	3.332
	1.98	3.757
	1.50	4.013
Jan. 26, a. m.	1.08	4.264
Jan. 27, a. m.	1.98	3.736
	1.49	4.021
Jan. 28, a. m.	1.98	3.766
	1.50	4.007
Jan. 29, a. m.	1.13	4.091
Jan. 30, a. m.	1.33	4.029
Jan. 31, a. m.	1.97	3.595
	1.49	3.802
Feb. 6, p. m.	1.04	4.181
	1.01	4.176
Feb. 7, a. m.	1.71	3.563
Feb. 8, a. m.	1.11	4.102
	1.02	4.166
Feb. 9, a. m.	1.98	3.630
	1.49	3.924
Feb. 10, a. m.	4.89	2.562
	4.19	2.818
	3.57	3.035
	2.97	3.288
	1.99	3.750
	1.49	4.055
Feb. 11, a. m.	1.97	3.806
	1.25	4.271
Feb. 12, a. m.	1.02	4.426
Feb. 13, a. m.	1.03	4.272
	1.02	4.194
Feb. 14, a. m.	1.98	3.554
	1.49	3.873
Feb. 15, p. m.	1.02	4.213
Feb. 16, a. m.	1.99	3.691
	1.49	3.998
Feb. 18, a. m.	1.22	4.131
Feb. 19, a. m.	2.95	3.279
	1.98	3.717
Feb. 20, p. m.	1.99	3.826
Feb. 24, p. m.	1.06	4.252
	1.04	4.272
Feb. 25, a. m.	4.82	2.539
	4.13	2.747
	3.53	2.969
	2.94	3.207
	1.98	3.693
	1.49	3.982
Feb. 26, a. m.	2.91	3.233
	1.98	3.653
Feb. 27, a. m.	1.49	3.992
	1.36	4.086
Feb. 28, p. m.	1.09	4.239
	1.03	4.280
Mar. 1, p. m.	1.26	4.023
Mar. 2, a. m.	1.97	3.608
	1.49	3.920
Mar. 3, a. m.	2.96	2.930
	1.99	3.478
	1.49	3.842
Mar. 5, p. m.	1.37	3.969
Mar. 6, a. m.	1.27	4.038
Mar. 7, a. m.	1.14	4.168
Mar. 8, a. m.	1.20	4.053
Mar. 10, a. m.	1.32	4.099
	1.24	4.173
Mar. 11, a. m.	4.93	2.779
	4.20	2.977
	3.57	3.165
	2.97	3.380
	2.44	3.626
	1.98	3.831
	1.49	4.093
	1.36	4.155
	1.24	4.200
	1.16	4.264
	1.10	4.305
	1.07	4.328
	1.06	4.354
Mar. 11, p. m.	1.06	4.338
	1.08	4.332
	1.13	4.297
	1.19	4.268
	1.30	4.210
	1.43	4.125
	1.53	4.080
	2.01	3.826
	2.50	3.608
	3.00	3.365
	3.69	3.154
	4.29	2.963
	5.03	2.746
Mar. 12, a. m.	1.99	3.710
	1.49	3.937
Mar. 13, a. m.	2.95	3.270
	1.99	3.715
	1.50	3.973
Mar. 14, a. m.	4.88	2.738
	4.18	2.958
	3.56	3.148
	2.95	3.370
	1.98	3.784
	1.49	4.055
Mar. 15, a. m.	2.95	3.457
	1.98	3.874
	1.50	4.115
Mar. 16, a. m.	1.98	3.782
	1.49	4.068
Mar. 17, a. m.	4.90	2.578
	4.17	2.805
	3.56	3.018
	2.96	3.227
	1.99	3.708
	1.49	3.979
Mar. 18, a. m.	2.96	3.249
	1.99	3.742
	1.49	4.027
Mar. 19, a. m.	1.29	4.018
	1.22	4.110
Mar. 20, a. m.	1.26	4.063
	1.21	4.022
Mar. 21, a. m.	2.95	3.049
	1.98	3.571
	1.50	3.843
Mar. 23, a. m.	1.99	3.338
	1.49	3.671
Mar. 24, a. m.	2.00	3.468
	1.50	3.736
Mar. 26, a. m.	1.89	3.632
	1.50	3.849
Mar. 27, a. m.	4.83	3.007
	4.14	3.231
	3.54	3.425
	2.96	3.628
	1.99	3.986
	1.50	4.212
Mar. 28, a. m.	2.96	3.632
	1.98	4.069
	1.49	4.269
Mar. 29, a. m.	4.86	2.961
	4.16	3.107
	3.55	3.279
	2.97	3.522
	2.00	3.912
	1.50	4.112
Mar. 30, a. m.	4.87	2.963
	4.17	3.122
	3.56	3.289
	2.97	3.511
	1.99	3.924
	1.49	4.098
Mar. 31, a. m.	4.81	2.851
	4.13	3.025
	3.54	3.254
	2.72	3.560
	1.98	3.901
	1.49	4.093
Apr. 1, a. m.	4.83	2.753
	4.14	2.919
	3.54	3.117
	2.96	3.296
	1.99	3.756
	1.50	4.009
Apr. 2, a. m.	2.96	3.333
	2.00	3.785
Apr. 3, a. m.	1.80	3.932
	1.50	4.072
Apr. 4, a. m.	2.97	3.436
	1.99	3.941
Apr. 5, a. m.	2.96	3.312
	1.98	4.004
	1.48	4.202
Apr. 6, a. m.	4.92	2.800
	4.20	3.006
	3.59	3.150
	2.96	3.323
	1.98	3.839
	1.49	4.083

[1] To reduce readings of Pyrheliometer S. I. 30 to calories (Smithsonian Revised Pyrheliometry of 1913) multiply by 0.3605.

Table 29.—*Pyrheliometer readings, Calama, Chile, 1920*—Continued.

M.	R.
Apr. 7, a. m.	
2.96	3.507
1.98	3.914
1.50	4.126
Apr. 8, a. m.	
2.97	3.511
1.98	3.921
1.50	4.333
Apr. 9, a. m.	
4.94	2.877
4.22	3.079
3.61	3.285
2.98	3.493
1.98	3.938
1.49	4.177
Apr. 10, a. m.	
4.92	3.006
4.22	3.171
3.61	3.414
2.95	3.607
1.99	3.989
1.50	4.246
Apr. 11, a. m.	
1.76	4.165
1.50	4.305
Apr. 12, a. m.	
1.56	4.065
1.50	4.110
Apr. 13, a. m.	
4.94	2.875
4.23	3.110
3.61	3.197
2.96	3.564
1.98	3.917
1.50	4.130
Apr. 14, a. m.	
4.85	3.047
4.17	3.280
3.57	3.466
2.97	3.644
1.98	4.048
1.49	4.251
Apr. 15, a. m.	
2.91	3.551
1.98	3.980
1.50	4.229
Apr. 16, a. m.	
2.98	3.464
1.99	3.945
1.50	3.962
Apr. 17, a. m.	
4.89	2.745
4.19	2.959
3.60	3.170
2.92	3.453
2.02	3.860
Apr. 18, a. m.	
2.97	3.412
2.00	3.834
Apr. 19, a. m.	
4.93	2.742
4.25	2.914
3.64	3.178
2.95	3.413
2.00	3.801
1.50	4.055
Apr. 20, a. m.	
2.96	3.435
2.00	3.841
1.50	4.076
Apr. 21, a. m.	
2.97	3.311
1.99	3.757
1.50	3.951
Apr. 22, a. m.	
4.81	2.936
4.16	3.100
3.56	3.301
2.98	3.502
1.99	3.832
1.49	4.146
Apr. 23, a. m.	
2.96	3.474
1.99	3.840
1.49	4.044
Apr. 24, a. m.	
1.33	4.197
Apr. 25, a. m.	
2.96	3.365
1.99	3.751
Apr. 26, a. m.	
4.91	2.896
4.22	3.009
3.63	3.298
2.98	3.501
1.99	3.886
1.49	4.107
Apr. 27, a. m.	
4.91	2.734
4.23	2.919
3.64	3.144
2.99	3.510
2.00	3.865
1.49	4.090
Apr. 28, a. m.	
1.33	4.034
Apr. 29, a. m.	
1.99	3.874
1.49	4.112
Apr. 30, a. m.	
1.28	4.188
1.27	4.198
May 1, a. m.	
1.40	4.095
May 2, a. m.	
3.01	3.650
1.98	4.059
May 3, a. m.	
4.96	3.048
4.28	3.241
3.68	3.407
2.99	3.636
1.99	4.023
1.50	4.178
May 4, a. m.	
2.97	3.581
1.99	3.971
1.50	4.184
May 5, a. m.	
2.98	3.405
1.98	3.935
May 6, a. m.	
2.98	3.602
1.99	4.023
May 7, a. m.	
4.80	2.979
4.16	3.164
3.60	3.340
2.95	3.577
2.00	3.990
1.50	4.130
May 8, p. m.	
3.07	3.632
2.18	3.969
May 9, a. m.	
2.26	3.752
1.99	3.891
May 10, a. m.	
2.97	3.432
1.99	3.985
1.47	4.144
May 11 a. m.	
4.98	3.069
4.31	3.281
3.66	3.436
2.97	3.686
2.00	4.061
1.50	4.246
May 12, a. m.	
2.97	3.641
1.99	3.999
1.48	4.245
May 13, a. m.	
2.47	3.751
1.98	3.981
May 14, a. m.	
4.91	2.671
4.25	2.942
3.63	3.052
2.99	3.292
2.48	3.592
2.02	3.834
May 16, a. m.	
2.99	3.571
2.38	3.794
2.00	3.977
May 17, a. m.	
2.97	3.514
2.48	3.711
1.99	3.990
May 18, a. m.	
2.47	3.559
1.98	3.764
May 20, a. m.	
4.97	3.105
4.31	3.211
3.68	3.436
2.97	3.681
2.47	3.849
1.99	3.937
May 21, a. m.	
2.94	3.634
2.46	3.828
May 22, a. m.	
2.98	3.505
2.49	3.693
1.99	3.999
May 23, a. m.	
2.99	3.641
2.49	3.830
1.99	4.064
May 24, a. m.	
1.67	4.007
1.50	4.112
May 25, a. m.	
2.00	3.914
1.90	3.965
May 26, a. m.	
2.99	3.452
1.99	3.856
May 27, a. m.	
3.00	3.741
2.46	3.923
1.99	4.099
May 28, a. m.	
2.98	3.662
2.48	3.853
1.98	4.050
May 29, a. m.	
2.47	3.761
1.98	4.037
May 30, a. m.	
4.96	3.147
4.32	3.414
3.69	3.596
2.99	3.828
2.47	3.984
1.99	4.155
May 31, a. m.	
2.48	3.767
1.97	4.064
June 1, a. m.	
2.49	3.739
1.99	3.956
June 2, a. m.	
4.83	3.243
4.22	3.392
3.63	3.560
2.98	3.764
2.50	3.912
1.99	4.076
June 3, a. m.	
2.97	3.770
2.48	3.970
1.98	4.109
June 4, a. m.	
1.73	4.029
1.67	4.066
June 5, a. m.	
2.98	3.690
2.50	3.865
June 6, a. m.	
2.97	3.615
2.49	3.779
1.98	3.972
June 7, a. m.	
2.93	3.577
2.47	3.716
1.99	3.905
June 8, a. m.	
2.49	3.742
1.99	3.915
June 9, a. m.	
2.48	3.848
1.99	4.058
June 10, a. m.	
2.45	3.956
1.90	4.149
June 11, a. m.	
1.99	4.122
1.91	4.169
June 12, a. m.	
2.98	3.621
2.49	3.812
1.98	4.015
June 13, a, m.	
1.60	4.138
1.57	4.161
June 14, a. m.	
1.95	3.849
1.88	3.903
June 15, a. m.	
3.01	3.522
2.51	3.728
June 18, p. m.	
1.98	3.870
1.81	3.926
June 19, p. m.	
1.52	4.114
1.50	4.126
June 23, a. m.	
1.72	4.003
1.67	4.027
June 24, a. m.	
4.91	3.177
4.29	3.314
3.69	3.461
3.00	3.724
2.48	3.873
2.00	4.015
June 25, a. m.	
2.97	3.464
2.48	3.670
June 26, a. m.	
2.99	3.551
2.49	3.733
1.99	3.878
June 27, a. m.	
1.97	3.759
June 30, a. m.	
4.94	2.995
4.31	3.123
3.70	3.307
2.98	3.517
2.49	3.642
1.98	3.895
July 1, a. m.	
2.99	3.705
1.75	4.165
July 2, a. m.	
2.94	3.803
2.01	4.097
July 3, a. m.	
3.01	3.620
1.99	4.026
July 4, a. m.	
2.11	3.972
2.00	4.030

TABLE 29.—*Pyrheliometer readings, Calama, Chile, 1920*—Continued.

M.	R.	M.	R.	M.	R.	M.	R.	M.	R.	M.	R.	M.	R.
July 5, a. m.		July 7, a. m.		July 9, a. m.		July 11, a. m.		July 15, a. m.		July 20, a. m.		July 24, a. m.	
2.99	3.721	2.98	3.617	1.82	4.080	2.07	3.892	2.48	3.577	2.97	3.504	1.81	3.977
2.47	3.898	2.48	3.817	1.72	4.110	1.97	3.934	1.88	3.780	1.99	3.873	July 25, p. m.	
1.99	4.071	1.99	3.993	July 10, a. m.		July 12, a. m.		July 18, a. m.		July 21, a. m.		1.86	3.986
July 6, a. m.		July 8, a. m.		2.46	3.746	2.97	3.573	3.00	3.459	2.96	3.458	July 26, a. m.	
1.44	4.236	1.99	4.074	2.00	3.894	3.47	3.728	July 19, a. m.		July 22, a. m.		1.95	4.019
1.43	4.193	1.91	4.136	1.92	3.943			2.97	3.469	1.46	4.080		

MEAN VALUES OF THE RADIATION OBSERVED AT MOUNT WILSON.

Prof. Kimball has been publishing in the Monthly Weather Review for a number of years the pyrheliometric values obtained at Washington, Madison, Lincoln, and Santa Fe by Weather Bureau observers. The publication of such matter in this form is very useful and we give here similar values as obtained by our own observers at Mount Wilson.

It seems unnecessary to give here the values for several different air masses as Prof. Kimball has done, because the kind of information which would be obtained in this way can be obtained by the reader from the table of solar constant values under the heading "Apparent Atmospheric Transmission." We have selected values close to air mass 2 and have reduced them so as to give the monthly mean intensity of solar radiation at the station in calories per square centimeter per minute at air mass 2. We give also the values as reduced to mean solar distance. The period of observation extends from 1905 to the present time for several months of each year excepting 1907. This period includes more than a complete sun-spot cycle. We have taken the mean values for each month for the years 1905 to 1916 all reduced to mean solar distance as representative of the whole of one sun-spot cycle of 11 years. Using these monthly mean values as a basis we have computed the departures for the individual months.

TABLE 30.—*Average monthly pyrheliometer results.*

[Expressed in calories per cm² per minute.]

Year.	May.			June.			July.			August.		
	As observed.	At mean solar distance.	Departure.	As observed.	At mean solar distance.	Departure.	As observed.	At mean solar distance.	Departure.	As observed.	At mean solar distance.	Departure.
1905	1.310	1.342	−24	1.413	1.459	+61	1.365	1.410	+ 40	1.341	1.373	+ 3
1906	1.356	1.388	+22	1.373	1.421	+23	1.281	1.323	− 47	1.347	1.380	+ 10
1908	1.325	1.360	− 6	1.315	1.357	−41	1.311	1.355	− 15	1.340	1.374	+ 4
1909	...	...	...	1.331	1.374	−24	1.364	1.409	+ 39	1.336	1.369	− 1
1910	1.354	1.389	+23	1.375	1.419	+21	1.338	1.383	+ 13	1.343	1.377	+ 7
1911	...	...	...	1.341	1.385	−13	1.335	1.380	+ 10	1.399	1.435	+ 65
1912	1.319	1.349	−17	1.349	1.392	− 6	1.165	1.204	−166	1.103	1.131	−239
1913	...	...	...	...	...	...	1.234	1.274	− 96	1.237	1.269	−101
1914	...	...	...	1.340	1.384	−14	1.311	1.354	− 16	1.315	1.348	− 22
1915	...	...	...	1.365	1.409	+11	1.370	1.416	+ 46	1.373	1.408	+ 38
1916	...	...	...	1.337	1.381	−17	1.356	1.401	+ 31	1.331	1.362	− 8
1917	...	...	...	...	...	...	1.254	1.296	− 74	1.328	1.361	− 9
1918	...	...	...	1.258	1.300	−98	1.335	1.379	+ 9	1.319	1.353	− 17
1919	...	...	...	1.359	1.404	+ 6	1.280	1.322	− 48	1.291	1.324	− 46
1920	...	...	...	...	...	...	1.343	1.388	+ 18	1.284	1.317	− 53
Mean[1]	...	1.366	...	...	1.398	...	...	1.370	...	...	1.370	...

Year.	September.			October.			November.		
	As observed.	At mean solar distance.	Departure.	As observed.	At mean solar. distance.	Departure,	As observed.	At mean solar distance.	Departure.
1905	1.372	1.386	− 7	1.421	1.413	− 1	...	...	...
1906	1.400	1.417	+ 24	1.450	1.443	+29	...	...	...
1908	1.356	1.372	− 21	1.428	1.417	+ 3	1.448	1.418	−12
1909	1.397	1.413	+ 20	1.442	1.434	+20	...	...	...
1910	1.412	1.426	+ 33	1.426	1.416	+ 2	1.474	1.448	+18
1911	1.417	1.436	+ 43	1.465	1.458	+44	1.482	1.475	+45
1912	1.050	1.068	−325	...	...	...	...	...	...
1913	1.297	1.310	− 83	1.348	1.339	−75	1.404	1.378	−52
1914	1.385	1.402	+ 9	1.386	1.380	−34	...	...	...
1915	1.378	1.392	− 1	1.448	1.442	+28	...	...	...
1916	1.361	1.374	− 19	1.402	1.393	−21	...	...	...
1917	1.377	1.391	− 2	1.363	1.362	−52	...	...	...
1918	1.398	1.413	+ 20	1.401	1.397	−17	...	...	...
1919	1.371	1.389	− 4	...	...	...	...	...	...
1920	1.288	1.301	− 92	...	...	...	...	...	...
Mean[1]	...	1.393	...	...	1.414	...	...	1.430	...

[1] 1905–1916, inclusive, used in getting mean. Last three values in 1912 excluded because abnormally low owing to the volcanic eruption of June 6 at Mount Katmai, Alaska.

The outstanding feature is the great depression in the values of radiation for the months of July and August, 1912, due to the eruption of the volcano of Katmai in Alaska, which occurred June 6, 1912. The fine dust from this eruption was still remaining in the atmosphere to some extent in 1913 but the influence of it upon the pyrheliometric values was not large in 1914. In comparison with this terrestrial volcanic outburst, the effect of solar activities upon pyrheliometric values was not very great. There is perhaps a slight tendency towards diminishing values attending increasing solar activity, as if the sky was less clear at such times. The same tendency, as is well recognized, is found in terrestrial temperatures. On the contrary, as will appear below, the solar radiation outside our atmosphere is higher at times of increased solar activity.

DETERMINATIONS OF THE SOLAR CONSTANT OF RADIATION BY THE METHOD OF HIGH AND LOW SUN OBSERVATIONS OF HOMOGENEOUS RAYS AND THE ATMOSPHERIC TRANSMISSION FOR DIFFERENT WAVE LENGTHS.

We now give in condensed form the result of independent determinations of the solar constant of radiation by the spectrobolometric method. They were obtained in part at Mount Wilson, California, at latitude 34° 12′ 55″ N., longitude 118° 3′ 34″ W., elevation 1,737 meters; in part at Hump Mountain,[2] North Carolina, at latitude 36° 8′ N., longitude 82° 0′ W., altitude 1,500 meters; and in part at Calama, Chile, latitude 22° 28′ S., longitude 68° 56′ W., altitude 2,250 meters. Prior to July, 1919, the solar-constant results were all reached by the complex process of combining spectrum measurements by the bolometer with pyrheliometric observations after the manner described in Volumes II and III of these Annals. Since July, 1919, a large part of the values obtained at Calama, Chile, have been obtained by the shorter method, depending upon observations of the brightness of the sky with the pyranometer in combination with the measurements of the spectrobolometer and pyrheliometer as described in Chapter II of the present volume. Whether obtained by the older process or the new the solar-constant values are believed to represent closely the actual intensity of the solar radiation as it is in space at the earth's mean distance from the sun, and not to be much affected by absorption or scattering within the earth's atmosphere. All of the determinations of radiation are expressed in calories per square centimeter per minute according to the scale of Smithsonian Revised Pyrheliometry of 1913.

SOLAR CONSTANT AND ATMOSPHERIC TRANSMISSION AT MOUNT WILSON, 1912 TO 1920.

The following tables, uniform with those which appeared on pages 104 to 112 of Volume III of the Annals, give the results obtained at Mount Wilson for the years 1912 to 1920. Column 1 gives the date; column 2 the pressure of aqueous vapor prevailing during the observations expressed in millimeters of mercury. Column 3, "precipitable water," gives the depth of liquid water which would be produced by condensing all the water vapor in the atmosphere vertically above the observer. Columns 4, 5, and 6 relate to pyrheliometry. The grade of the pyrheliometric observation is given in column 4 (e signifies excellent; vg, very good; g, good; and p, poor). The grade depends upon whether the observations of the pyrheliometer, when plotted logarithmically against the air mass (which is nearly proportional to the secant of the zenith distance) yield approximately straight lines.[3] Column 5 is the apparent atmospheric transmission, "a." It is derived from the logarithmic plots just mentioned by measuring the tangent of the inclination of the best representative line, giving weight to the part covering air masses less than 3.0. This tangent is the logarithm of "a," the apparent atmospheric transmission. Column 6 gives

[2] Owing to excessive humidity and cloudiness the Hump Mountain results are seldom of much weight.

[3] If perfect these logarithmic representative pyrheliometric lines should be slightly concave toward the origin as already explained.

the apparent solar constant, which we call "A_o." It is found from the logarithmic plot just mentioned by producing the best straight line and determining its intercept on the axis of ordinates. This intercept is the logarithm of the apparent solar constant "A_o" as it was originally determined according to the method of Pouillet.

To avoid misunderstandings such as have hitherto occurred, we repeat that these values of "A_o" and "*a*" are given knowing them to be necessarily inexact from theoretical reasons and only because they are useful indices of the general character of the day and of the transmission of the atmosphere upon it. The values "A_o," like the values of the solar constant "E_o," given in the same table at a later column, are reduced to mean solar distance. We emphatically disclaim, however, any intention of indicating that the "solar constant" may be obtained by pyrheliometry alone by any process whatever with anything but a rough degree of approximation. It is absolutely necessary for its determination to investigate the distribution of rays in the solar spectrum. As shown by Langley, the pyrheliometry alone must always yield a value A_o less than the true intensity of the beam outside the atmosphere.

Columns 7 to 21 give the results of spectrobolometric work and of this combined with pyrheliometry. The principal result of the whole table is E'_o given in column 21, which expresses the intensity of solar radiation outside the atmosphere at the earth's mean distance from the sun. It is found by combining pyrheliometry and bolometry according to the method of Langley, as explained in Chapter I in Volume III of these Annals, but with a correction applied to the preliminary result (E_o, found in column 18) in order to allow for the residual effect of water vapor discussed in Chapter III of the Annals, Volume III.[4] Column 7 gives the grade of the determination of the solar constant. It depends mainly on the approximation of the logarithmic transmission plots to straight lines. Columns 8 to 17 give the coefficients of atmospheric transmission for different wave lengths. They indicate the fraction of the light of a given wave length which would be transmitted from a celestial body in the zenith to the observing station. Column 19 gives the ratio of the true corrected solar constant E'_o, found in column 21, to the apparent solar constant A_o determined by the method of Pouillet as found in column 6. Column 20 gives the true atmospheric transmission for all wave lengths combined. It is found by multiplying the values of the apparent solar constant A_o, given in column 6, by the apparent atmospheric transmission "*a*", given in column 5, and dividing the product by the corrected solar constant of radiation E'_o, given in column 21.

[4] As noted below, however, we have not found it necessary to similarly correct the Chilean values.

TABLE 31.—*Solar-constant values, Mount Wilson, 1912.*

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry. Grade.	Pyrheliometry. Apparent atmospheric transmission a.	Pyrheliometry. Apparent solar constant A_o.	Bolometry. Grade.	Atmospheric transmission for different wave lengths. μ 0.35	μ 0.40	μ 0.45	μ 0.50	μ 0.60	μ 0.70	μ 0.80	μ 1.00	μ 1.20	μ 1.60	Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.
	mm.	*mm.*																		
Apr. 27	5.53	2.8	e.	0.900	1.749	g.+	0.597	0.720	0.799	0.850	0.886	0.922	0.954	0.975	0.981	0.986	1.894	1.086	0.829	1.900
May 1	6.00	3.2	g.	.872	1.650	p.	.541	.665	.747	.799	.841	.915	.947	.966	.969	.974	1.894	1.152	.757	1.900
3	3.55	3.1	v.g.+	.910	1.764	v.g.	.604	.731	.816	.868	.890	.937	.965	.971	.973	.971	1.944	1.105	.823	1.950
4	4.90	5.1	v.g.+	.861	1.813	v.g.—	.584	.704	.781	.824	.844	.899	.930	.942	.946	.952	1.965	1.090	.790	1.976
5	4.13	7.6	e.	.851	1.822	v.g.+	.564	.684	.765	.813	.850	.900	.916	.930	.932	.934	1.966	1.087	.782	1.982
10	6.40	9.6	v.g.	.876	1.749	g.	.572	.701	.787	.830	.860	.909	.942	.965	.969	.975	1.919	1.108	.791	1.938
11	4.10	8.0	v.g.	.876	1.760	v.g.	.575	.710	.792	.846	.885	.931	.955	.970	.972	.972	1.904	1.091	.803	1.920
12	4.26	10.4	e.	.848	1.772	g.	.520	.668	.750	.805	.836	.884	.918	.940	.941	.944	1.983	1.131	.749	2.005
13	2.74	4.4	v.g.+	.851	1.810	g.—	.538	.689	.776	.820	.844	.895	.911	.921	.923	.926	1.965	1.091	.780	1.974
14	4.44	6.1	e.	.864	1.736	e.—	.553	.679	.769	.820	.844	.900	.925	.945	.948	.952	1.906	1.105	.782	1.918
15	4.90	6.6	g.	.838	1.826	g.—	.585	.695	.775	.821	.850	.909	.925	.934	.934	.934	1.920	1.059	.792	1.933
20	3.26	7.4	e.	.872	1.744	v.g.	.607	.719	.784	.831	.873	.915	.940	.950	.952	.950	1.919	1.109	.786	1.934
22	4.09	7.5	v.g.	.879	1.658	p.	.540	.694	.776	.825	.860	.932	.951	.962	.964	.969	1.840	1.119	.786	1.855
23	4.30	10.3	v.g.	.867	1.763	g.	.596	.713	.791	.839	.870	.916	.931	.945	.955	.968	1.940	1.112	.779	1.961
28	5.00	9.1	e.	.902	1.730	e.—	.623	.750	.826	.869	.901	.941	.960	.968	.972	.973	1.920	1.120	.805	1.938
30	5.85?	3.8	v.g+.	.904	1.780	e.—	.599	.737	.820	.848	.885	.934	.956	.974	.977	.976	1.979	1.116	.810	1.987
31	2.94	5.4	v.g.—	.908	1.746	g.+	.611	.745	.826	.881	.909	.949	.962	.967	.968	.972	1.894	1.090	.832	1.905
June 1	3.96	6.1	v.g.	.906	1.735	e.—	.615	.741	.830	.868	.900	.948	.970	.975	.975	.980	1.914	1.110	.816	1.926
1[1]	4.70	10.0	g.	.845	1.717	v.g.	.499	.654	.756	.810	.855	.901	.932	.942	.944	.942	1.896	1.116	.757	1.916
2	4.72	5.7	v.g.	.887	1.787	e.	.588	.720	.800	.854	.875	.928	.951	.960	.965	.964	1.952	1.098	.808	1.964
3	3.94	6.6	v.g.	.897	1.734	e.	.624	.749	.825	.872	.896	.949	.969	.972	.977	.979	1.909	1.108	.809	1.922
3[1]	4.85	8.0	v.g.—	.883	1.724	v.g.—	.550	.690	.774	.825	.865	.915	.938	.961	.975	.979	1.956	1.143	.772	1.973
4	5.08	6.5	e.	.916	1.665	g.+	.628	.750	.831	.885	.907	.958	.970	.975	.977	.979	1.848	1.117	.819	1.861
5	5.47	8.5	e.	.904	1.717	e.—	.618	.750	.824	.863	.898	.961	.980	.988	.985	.985	1.871	1.099	.822	1.888
6	5.22	10.6	v.g.	.889	1.733	g.+	.583	.726	.824	.862	.886	.934	.954	.960	.964	.971	1.873	1.092	.814	1.894
7	3.43	4.1	e.	.908	1.766	e.	.611	.744	.826	.879	.906	.942	.956	.970	.970	.971	1.931	1.098	.826	1.940
7[1]	5.40	4.0	v.g.+	.914	1.702	g.	.615	.730	.825	.880	.921	.965	.978	.980	.980	.984	1.858	1.096	.834	1.866
8	4.13	5.9	v.g.	.900	1.746	e.—	.624	.745	.828	.881	.912	.945	.962	.969	.970	.970	1.903	1.096	.820	1.915
9	3.46	5.3	e.—	.897	1.745	v.g.	.645	.744	.803	.850	.886	.940	.971	.980	.982	.982	1.901	1.095	.819	1.912
10	5.74	8.6	e.—	.873	1.755	g.	.585	.701	.785	.824	.866	.910	.935	.962	.973	.979	1.919	1.102	.791	1.936
11	5.98	12.1	e.	.881	1.714	e.—(?)	.556	.690	.770	.822	.860	.917	.960	.978	.979	.985	1.915	1.131	.779	1.940
13	9.35	12.4	v.g.—	.900	1.694	g.	.604	.747	.840	.886	.909	.959	.970	.979	.983	.983	1.869	1.118	.805	1.894
14	5.30	6.4	v.g.	.906	1.758	v.g.	.621	.756	.842	.877	.890	.946	.972	.980	.981	.980	1.915	1.096	.826	1.928
15	3.75	4.4	v.g.+	.902	1.800	g.	.594	.746	.830	.874	.901	.940	.960	.981	.983	.980	1.947	1.086	.829	1.956
16	4.34	6.9	g.	.883	1.789	v.g.	.611	.729	.805	.850	.878	.930	.948	.955	.957	.959	1.937	1.090	.809	1.951
17	3.53	3.6	e.	.895	1.771	v.g.	.573	.719	.814	.864	.888	.935	.960	.960	.959	.960	1.955	1.110	.806	1.967
18	3.05	4.0	e.	.906	1.770	e.	.605	.730	.809	.859	.920	.971	.977	.983	.982	.984	1.922	1.090	.831	1.930
19	3.99	5.3	e.—	.891	1.772	e.	.598	.713	.792	.844	.877	.920	.958	.976	.977	.975	1.920	1.090	.818	1.931
20	5.14?	5.8	e.—	.900	1.742	g.	.615	.737	.812	.861	.885	.942	.960	.969	.970	.974	1.915	1.105	.814	1.926
25	4.55	5.6	g.	.855	1.855	v.g.	.520	.656	.752	.815	.850	.900	.932	.945	.950	.956	2.004	1.086	.787	2.016
25[1]	4.27	4.8	e.	.895	1.755	p.	.566	.700	.780	.831	.894	.933	.960	.973	.977	.981	1.966	1.126	.795	1.976
26	2.35	5.1	v.g.	.906	1.747	v.g.	.585	.716	.797	.851	.890	.940	.960	.971	.974	.975	1.896	1.091	.830	1.906
27	2.62	7.8	e.	.895	1.769	v.g.	.590	.725	.806	.860	.906	.964	.975	.985	.990	.993	1.917	1.092	.819	1.933
30	3.57	3.6	e.	.841	1.759	v.g.	.480	.617	.700	.755	.815	.865	.898	.927	.935	.940	1.938	1.106	.760	1.946
July 1	4.23	3.6	g.+	.916	1.522	v.g.	.606	.734	.811	.864	.912	.955	.977	.984	.986	.986	1.646	1.085	.844	1.652
4	5.55	8.7	v.g.	.787	1.797	v.g.	.445	.575	.660	.720	.778	.836	.879	.908	.918	.926	1.954	1.041	.756	1.872
5	4.82	6.4	v.g.	.867	1.751	v.g.+	.525	.659	.740	.802	.858	.911	.935	.953	.959	.961	1.940	1.115	.778	1.953
5[1]	5.48	9.8	g.	.838	1.739	g.	.524	.661	.748	.810	.852	.916	.950	.960	.965	.968	1.843	1.071	.783	1.862
6	3.68	8.2	e.	.822	1.820	g.	.444	.583	.671	.736	.794	.850	.897	.935	.952	.957	2.043	1.132	.725	2.062
7	4.73	7.2	e.—	.836	1.774	v.g.	.515	.642	.726	.783	.825	.885	.912	.939	.950	.950	1.940	1.101	.758	1.955
8	4.81	7.6	e.[2]	.925	1.728	e.	.555	.670	.749	.800	.825	.890	.935	.958	.962	.971	1.887	1.100	.841	1.902
9	5.87	8.4	v.g.+	.869	1.734	g.	.491	.647	.740	.805	.854	.915	.960	.979	.982	(.990)	1.925	1.120	.776	1.942
11	4.66	15.5	g.	.834	1.699	g.—	.539	.672	.759	.809	.850	.896	.925	.946	.955	.968	1.839	1.100	.759	1.870

[1] Afternoon observations. All others were made before noon.

TABLE 31.—*Solar-constant values, Mount Wilson, 1912*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry. Grade.	Pyrheliometry. Apparent atmospheric transmission a.	Pyrheliometry. Apparent solar constant A_o.	Bolometry. Grade.	Bolometry. Atmospheric transmission for different wave lengths. 0.35 μ	0.40 μ	0.45 μ	0.50 μ	0.60 μ	0.70 μ	0.80 μ	1.00 μ	1.20 μ	1.60 μ	Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.
	mm.	*mm.*																		
July 12	7.54	11.0	v.g.+	0.865	1.731	e.—	0.558	0.687	0.770	0.820	0.850	0.906	0.929	0.950	0.958	0.969	1.913	1.117	0.774	1.935
12[1]	7.51	10.6	e.—	.822	1.820	v.g.	.531	.635	.708	.758	.818	.876	.908	.929	.937	.936	2.036	1.130	.727	2.059
13	6.09	14.5	e.	.820	1.707	g.	.517	.630	.706	.756	.805	.854	.885	.914	.925	.935	1.921	1.142	.718	1.951
14	7.11	12.5	v.g.—	.843	1.722	v.g.+	.549	.672	.750	.800	.847	.895	.913	.925	.930	.936	1.879	1.105	.763	1.904
19	10.76	17.9	g.—	.811	1.730	v.g.+	.489	.610	.692	.748	.785	.851	.890	.925	.939	.941	1.952	1.149	.705	1.990
19[1]	9.57	15.5	p.	.838	1.683	g.	.523	.662	.752	.795	.821	.853	.890	.942	.963	.978	1.905	1.150	.728	1.937
20	8.64	11.5	v.g.	.840	1.738	v.g.+	.545	.675	.755	.814	.855	.918	.946	.957	.964	.970	1.929	1.122	.747	1.953
20[1]	9.65	9.2	v.g.	.828	1.753	v.g.	.514	.620	.696	.750	.800	.861	.889	.910	.916	.921	1.998	1.150	.720	2.017
21	2.82	4.9	e.[2]	.851	1.681	v.g.	.531	.660	.735	.779	.822	.882	.914	.935	.943	.954	1.947	1.163	.731	1.956
22	3.66	9.0	g.+	.832	1.716	e.—	.545	.659	.728	.780	.820	.881	.910	.929	.932	.932	1.873	1.101	.755	1.891
23	3.74	4.8	v.g.	.843	1.801	g.	.530	.643	.715	.775	.815	.877	.911	.942	.955	.964	1.988	1.108	.760	1.998
23[1]	8.93	5.8	v.g.—	.855	1.756	v.g.—	.544	.671	.745	.795	.842	.900	.930	.942	.954	.965	1.872	1.072	.798	1.883
25	3.81	5.4	v.g.+	.832	1.772	g.	.490	.625	.717	.769	.804	.855	.888	.918	.930	.942	1.968	1.116	.745	1.979
26	5.65	5.8	e.—	.809	1.741	p.	.479	.595	.678	.726	.766	.820	.858	.899	.911	.935	1.929	1.115	.726	1.941
27	4.06	5.7	e.—	.832	1.734	v.g.	.517	.635	.709	.755	.800	.850	.889	.920	.932	.950	1.901	1.102	.754	1.912
31	6.49	12.8	e.	.780	1.647	v.g.+	.470	.577	.657	.711	.747	.796	.830	.874	.892	.914	1.849	1.137	.685	1.874
31[1]	7.06	17.1	g.+	.635	2.103	p.	.362	.470	.533	.575	.595	.650	.695	.724	.735	.740	2.411	1.166	.544	2.456
Aug. 1	4.24	5.1	p.	.769	1.743	p.	.428	.543	.619	.669	.713	.753	.798	.835	.847	.865	2.058	1.185	.648	2.069
2	6.44	5.2	g.	.692	1.573	e.	.372	.472	.538	.583	.621	.680	.730	.789	.814	.845	1.810	1.156	.598	1.820
3	1.32	3.5	e.	.791	1.760	e.	.505	.600	.656	.700	.745	.810	.842	.879	.900	.930	1.938	1.105	.716	1.945
4	3.70	4.4	e.	.800	1.723	e.	.500	.595	.656	.704	.750	.819	.860	.879	.888	.894	1.938	1.129	.708	1.947
5	3.58	4.8	e.	.814	1.734	e.	.523	.632	.695	.745	.783	.840	.876	.907	.919	.927	1.903	1.102	.738	1.913
6	3.98	5.4	e.	.817	1.726	e.—	.490	.619	.690	.740	.781	.825	.870	.896	.908	.929	1.924	1.120	.728	1.935
7	5.24	7.4	v.g.+	.813	1.734	e.	.522	.634	.700	.746	.780	.835	.865	.890	.904	.920	1.954	1.135	.716	1.969
8	4.98	7.0	e.[2]	.817	1.779	e.	.488	.610	.686	.739	.794	.858	.885	.914	.920	.932	1.967	1.113	.733	1.982
9	5.79	4.0	v.g.	.865	1.655	e.—	.555	.679	.749	.791	.819	.870	.915	.956	.970	.980	1.836	1.174	.737	1.944
10	4.83	8.4	v.g.	.736	1.801	e.—	.429	.535	.599	.630	.679	.746	.788	.830	.854	.885	2.057	1.151	.639	2.075
11	3.74	7.1	v.g.+	.828	1.708	v.g.	.485	.605	.680	.722	.790	.832	.868	.897	.905	.910	1.926	1.135	.729	1.940
12	4.32?	9.4	e.	.820	1.668	e.—	.499	.630	.715	.765	.800	.863	.839	.908	.915	.925	1.852	1.121	.731	1.870
13	3.58?	13.6	e.	.789	1.749	v.g.	.460	.590	.675	.730	.760	.815	.850	.888	.903	.913	1.994	1.157	.682	2.023
14	4.33?	6.0	e.—	.820	1.742	g.	.534	.638	.700	.750	.790	.830	.865	.910	.935	.965	1.941	1.121	.732	1.953
17	6.88	5.0	e.—	.753	1.809	e.	.453	.545	.605	.650	.696	.740	.782	.827	.850	.880	2.084	1.158	.650	2.095
18	5.92	4.9	e.—	.820	1.640	g.+	.508	.620	.686	.736	.780	.832	.860	.895	.912	.935	1.826	1.181	.695	1.937
19	6.92	7.5	e.	.736	1.854	v.g.+	.460	.560	.621	.662	.688	.740	.770	.820	.839	.866	2.116	1.151	.640	2.133
20	5.72	9.6	v.g.	.766	1.790	e.—	.468	.570	.628	.679	.715	.775	.810	.859	.885	.920	2.044	1.152	.664	2.065
21	4.46	7.2	v.g.+	.809	1.793	g.—	.475	.616	.694	.741	.780	.839	.869	.895	.905	.930	1.986	1.116	.725	2.001
22	7.32	12.8	e.	.834	1.748	g.	.545	.670	.740	.790	.842	.888	.915	.936	.942	.938	1.924	1.116	.747	1.951
23	2.98	14.4	v.g.+	.832	1.664	v.g.	.530	.644	.717	.767	.805	.872	.896	.920	.935	.956	1.962	1.197	.695	1.993
25	5.62	17.8	g.	.822	1.585	g.—	.525	.654	.729	.769	.809	.860	.888	.914	.925	.930	1.765	1.135	.724	1.799
26	4.39	17.1	e.	.813	1.569	p.	.484	.607	.685	.735	.781	.800	.840	.885	.908	.930	1.855	1.204	.675	1.890
27	3.18	3.7	e.—	.861	1.669	g.	.532	.670	.742	.790	.824	.873	.900	.920	.933	.944	1.888	1.135	.758	1.895
28	2.06	5.8	g.+	.863	1.709	p.	.534	.655	.740	.790	.833	.869	.900	.935	.946	.965	1.996	1.174	.735	2.008
29	8.31	7.2	e.—	.845	1.688	p.	.552	.669	.750	.799	.846	.877	.901	921	.930	.933	1.896	1.131	.747	1.910
30	5.08	4.1	v.g.	.843	1.592	v.g.—	.545	.658	.733	.785	.825	.862	.890	.919	.931	.936	1.775	1.119	.753	1.783
Sept. 1	5.20	6.8	v.g.	.798	1.744	v.g.+	.507	.598	.660	.713	.752	.810	.850	.880	.897	.916	1.955	1.128	.707	1.969
2	5.38	10.1	v.g.+	.807	1.778	v.g.+	.510	.633	.703	.750	.778	.835	.872	.902	.917	.937	1.964	1.116	.723	1.985
3	6.80	13.0	g.+	.828	1.568	v.g.	......	......	......	......	......	......	......	......	......	......	......	......	......	......
4	4.04	4.1	v.g.—	.733	1.679	p.	.445	.542	.603	.646	.682	.720	.766	.821	.850	.878	1.860	1.112	.669	1.868
5	5.03	4.9	e.	.771	1.811	v.g.+	.481	.592	.658	.699	.731	.781	.818	.860	.879	.900	2.014	1.117	.690	2.025

[1] Afternoon observations. All others were made before noon.

TABLE 32.—*Solar-constant values, Mount Wilson, 1913.*

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry. Grade.	Pyrheliometry. Apparent atmospheric transmission a.	Pyrheliometry. Apparent solar constant A_o.	Bolometry. Grade.	Atmospheric transmission for different wave lengths. 0.35μ	0.40μ	0.45μ	0.50μ	0.60μ	0.70μ	0.80μ	1.00μ	1.20μ	1.60μ	Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.
	mm.	*mm.*																		
July 16	3.44	14.3	e.—	0.855	1.722	v.g.+	0.543	0.682	0.767	0.824	0.852	0.906	0.933	0.959	0.969	0.980	1.902	1.121	0.762	1.932
23	6.45	11.7	g.	.865	1.711	v.g.—	.570	.691	.767	.812	.846	.912	.935	.951	.959	.966	1.914	1.132	.763	1.938
24	7.33	11.5	g.+	.869	1.685	v.g.+	.544	.689	.767	.817	.856	.921	.943	.964	.974	.981	1.890	1.134	.765	1.913
Aug. 3	7.28	13.9	v.g.+	.861	1.716	e.	.540	.682	.764	.814	.857	.910	.931	.949	.959	.967	1.903	1.125	.764	1.932
4	5.46	11.9	v.g.	.867	1.646	e.—	.575	.707	.789	.822	.861	.921	.950	.966	.967	.969	1.895	1.165	.744	1.919
5	2.05	5.4	g.+	.881	1.759	e.	.553	.690	.772	.821	.849	.910	.939	.958	.966	.976	1.948	1.113	.791	1.959
6	3.28	10.8	v.g.—	.875	1.702	v.g.—	.526	.680	.768	.816	.847	.914	.945	.969	.976	.984	1.894	1.125	.777	1.916
8	10.40	20.6	v.p.	.762	1.769	p.	.390	.516	.612	.675	.730	.815	.859	.897	.906	.911	2.016	1.165	.653	2.062
9	6.88	13.4	e.—	.813	1.717	e.	.480	.603	.679	.732	.790	.858	.894	.926	.942	.959	1.932	1.141	.712	1.960
10	6.76	13.0	g.	.853	1.681	v.g.—	.512	.645	.728	.780	.823	.885	.916	.952	.969	.974	1.929	1.163	.733	1.956
11	6.50	11.5	v.g.	.877	1.692	v.g.—	.575	.699	.775	.826	.862	.919	.939	.960	.972	.982	1.900	1.136	.771	1.923
12	5.40	5.9	e.—	.885	1.751	v.g.	.586	.710	.792	.847	.877	.927	.951	.970	.975	.976	1.928	1.107	.799	1.940
13	3.76	7.1	v.g.+	.890	1.714	v.g.	.572	.707	.793	.842	.868	.923	.951	.968	.975	.979	1.914	1.125	.791	1.928
14	3.22	6.5	v.g.	.883	1.757	e.—	.576	.714	.790	.837	.867	.917	.944	.959	.963	.960	1.942	1.112	.793	1.955
15	2.84	7.9	g.+	.869	1.753	e.—	.571	.703	.785	.830	.857	.926	.948	.956	.958	.959	1.907	1.096	.792	1.923
16	5.07	4.4	v.g.	.902	1.689	v.g.+	.582	.715	.798	.838	.858	.919	.950	.974	.981	.981	1.866	1.110	.812	1.875
17	6.06	5.2	e.—	.883	1.730	e.	.564	.703	.790	.845	.865	.925	.940	.954	.961	.974	1.903	1.105	.798	1.913
18	5.16	2.8	v.g.—	.883	1.812	v.g.+	.588	.715	.789	.838	.871	.920	.950	.967	.970	.975	1.952	1.080	.817	1.957
19	3.62	15.1	e.	.867	1.647	v.g.+	.571	.697	.773	.825	.852	.908	.933	.956	.957	.957	1.832	1.130	.767	1.862
20	10.40	26.1	e.—	.851	1.667	v.g.+	.529	.661	.740	.794	.842	.898	.923	.946	.954	.955	1.939	1.196	.711	1.995
21	10.45	22.3	e.	.855	1.662	v.g.—	.525	.672	.763	.815	.843	.904	.930	.952	.957	.967	1.871	1.152	.741	1.916
28	11.74	23.1	v.g.	.847	1.691	g.+	.560	.685	.764	.801	.842	.901	.925	.950	.956	.955	1.926	1.167	.725	1.975
Sept 2	5.55	8.9	v.g.—	.869	1.772	g.	.570	.704	.786	.822	.846	.914	.938	.959	.966	.967	1.946	1.108	.784	1.964
3	5.74	9.8	e.—	.873	1.721	e.+	.579	.699	.772	.825	.864	.924	.948	.960	.963	.968	1.916	1.124	.776	1.936
4	5.23	10.7	e.	.885	1.672	g.—	.592	.716	.793	.837	.870	.925	.945	.959	.962	.964	1.888	1.141	.774	1.910
5	4.68	11.7	v.g.—	.879	1.694	v.g.	.577	.711	.794	.836	.863	.925	.952	.971	.977	.981	1.884	1.126	.780	1.908
6	3.95	8.4	v.g.	.883	1.741	v.g.+	.574	.706	.792	.844	.877	.924	.953	.972	.976	.976	1.886	1.092	.808	1.903
7	4.86	11.3	g.	.865	1.720	v.g.+	.567	.688	.758	.811	.848	.908	.936	.955	.958	.968	1.929	1.135	.762	1.952
8	4.74	11.2	e.—	.873	1.680	v.g.+	.527	.678	.767	.819	.866	.924	.946	.958	.964	.967	1.876	1.129	.772	1.898
9	6.18	9.5	v.g.	.883	1.706	v.g.+	.565	.692	.773	.820	.865	.914	.939	.964	.972	.981	1.919	1.136	.777	1.938
10	5.43	11.9	e.—	.873	1.721	e.—	.584	.704	.773	.819	.862	.917	.938	.962	.975	.985	1.909	1.122	.777	1.933
11	6.79	13.2	v.g.+	.869	1.680	e.	.555	.694	.777	.826	.866	.918	.940	.953	.956	.958	1.887	1.139	.763	1.914
14	4.80	7.2	v.g.+	.893	1.702	e.—	.555	.716	.805	.853	.884	.935	.953	.964	.967	.972	1.894	1.120	.797	1.908
15	5.41	11.8	v.g.+	.875	1.704	v.g.+	.565	.695	.777	.826	.868	.928	.950	.966	.972	.982	1.877	1.115	.785	1.900
16	4.17	12.3	v.g.+	.875	1.719	v.g.—	.572	.716	.800	.841	.860	.919	.950	.972	.975	.982	1.889	1.112	.786	1.914
17	3.96	7.6	e.—	.883	1.746	g.+	.549	.699	.788	.837	.876	.932	.949	.963	.964	.968	1.924	1.110	.795	1.939
18	4.78	8.2	v.g.—	.853	1.802	v.g.+	.510	.650	.741	.795	.846	.907	.930	.950	.952	.958	1.978	1.106	.771	1.995
19	5.67	6.4	v.g.	.875	1.748	v.g.+	.545	.671	.762	.815	.853	.928	.949	.958	.962	.970	1.942	1.117	.782	1.955
21	8.0	16.5	v.g.	.887	1.644	v.g.+	.555	.695	.789	.844	.878	.937	.960	.969	.969	.971	1.885	1.167	.760	1.919
22	6.87	6.9	e.—	.881	1.741	v.g.+	.547	.703	.787	.837	.858	.915	.938	.956	.967	.971	1.940	1.121	.785	1.954
24	6.80	8.3	g.+	.807	1.782	e.	.465	.612	.690	.751	.801	.862	.893	.914	.920	.934	1.912	1.082	.745	1.929
25	2.84	4.3	v.g.+	.875	1.736	v.g.	.568	.692	.774	.826	.865	.910	.932	.955	.965	.968	1.873	1.083	.807	1.882
26	3.32	2.6	g.	.889	1.746	e.	.560	.698	.789	.837	.862	.924	.945	.978	.986	.991	1.844	1.058	.840	1.849
27	2.22	4.0	g.+	.881	1.746	e.	.568	.690	.770	.823	.859	.917	.939	.956	.963	.972	1.886	1.084	.812	1.894
28	2.51	4.3	v.g.—	.889	1.720	e.+	.599	.722	.795	.836	.869	.930	.950	.965	.974	.983	1.847	1.078	.824	1.855
29	4.04	3.2	e.—	.885	1.742	e.+	.572	.700	.777	.830	.870	.927	.945	.961	.969	.977	1.876	1.080	.818	1.883
30	2.54	3.0	v.g.	.881	1.718	g.+	.547	.681	.764	.810	.855	.912	.944	.960	.966	.978	1.901	1.110	.794	1.907
Oct. 1	4.54	9.3	v.g.+	.851	1.666	v.g.	.505	.638	.727	.788	.828	.890	.922	.947	.958	.974	1.852	1.121	.758	1.870
3	5.8	11.1	v.g.—	.832	1.748	v.g.—	.503	.625	.712	.771	.824	.886	.912	.934	.943	.954	1.945	1.125	.739	1.968
5	1.7	2.2	....	.893	1.598	p.	.555	.678	.759	.814	.853	.900	.928	.959	.980	.987	1.773	1.111	.803	1.777
6	2.4	2.1	v.g.	.889	1.720	v.g.	.600	.710	.784	.830	.859	.919	.941	.962	.974	.978	1.831	1.066	.833	1.835
7	3.7	4.2	e.	.873	1.718	e.	.579	.698	.768	.817	.855	.907	.933	.959	.968	.977	1.870	1.092	.799	1.878

TABLE 32.—*Solar-constant values, Mount Wilson, 1913*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry. Grade.	Pyrheliometry. Apparent atmospheric transmission *a*.	Pyrheliometry. Apparent solar constant A_o.	Bolometry. Grade.	Atmospheric transmission for different wave lengths. 0.35 μ	0.40 μ	0.45 μ	0.50 μ	0.60 μ	0.70 μ	0.80 μ	1.00 μ	1.20 μ	1.60 μ	Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$.	Solar constant corrected for zero water vapor E'_o.
	mm.	*mm.*																		
Oct. 8	3.2	5.3	v.g.	0.891	1.652	g.+	0.617	0.742	0.815	0.846	0.874	0.923	0.951	0.975	0.978	0.984	1.795	1.092	0.815	1.805
9	4.5	3.9	v.g.	.893	1.643	g.	.612	.740	.805	.835	.866	.918	.947	.969	.978	.986	1.799	1.099	.812	1.806
10	3.4	7.6	v.g.—	.871	1.743	v.g.—	.549	.692	.784	.827	.845	.896	.922	.943	.952	.960	1.970	1.139	.764	1.986
11	3.08	6.1	v.g.+	.885	1.726	e.+	.607	.717	.794	.845	.884	.932	.957	.979	.984	.987	1.841	1.073	.824	1.853
12	2.1	6.5	e.—	.885	1.741	e.+	.569	.711	.794	.842	.887	.943	.959	.972	.974	.979	1.881	1.087	.813	1.894
13	2.86	3.3	v.g.(?)	.920	1.583	p.	.585	.720	.813	.862	.889	.946	.963	.976	.984	.989	1.824	1.156	.796	1.830
14	3.4	3.4	g.	.887	1.767	e.	.590	.725	.806	.854	.879	.930	.956	.973	.980	.992	1.855	1.053	.941	1.862
15	3.25	3.0	v.g.+	.900	1.699	e.	.587	.717	.806	.847	.875	.930	.953	.974	.978	.981	1.826	1.078	.835	1.832
17	2.73	5.9	g.+	.881	1.748	e.—	.565	.699	.782	.835	.869	.927	.946	.966	.971	.970	1.896	1.091	.808	1.908
19	3.5	7.4	v.g.	.889	1.705	e.+	.593	.725	.824	.849	.885	.940	.961	.975	.980	.986	1.860	1.099	.809	1.875
20	3.4	4.6	e.—	.906	1.694	e.	.592	.721	.807	.853	.880	.924	.958	.975	.978	.986	1.860	1.102	.821	1.869
21	3.7	3.6	g.	.887	1.748	e.—	.561	.704	.787	.835	.868	.924	.948	.970	.980	.984	1.905	1.093	.812	1.912
22	3.1	7.5	....	.885	1.728	v.g.+	.591	.735	.819	.857	.885	.938	.955	.963	.965	.971	1.879	1.095	.807	1.894
23	4.2	8.6	v.g.+	.897	1.680	e.	.591	.736	.823	.864	.895	.942	.963	.976	.983	.990	1.856	1.114	.805	1.873
24	4.3	7.6	v.g.+	.900	1.714	e.	.594	.743	.826	.871	.898	.949	.967	.980	.980	.986	1.868	1.098	.819	1.883
25	3.8	4.2	g.+	.900	1.721	e.	.587	.736	.821	.866	.890	.931	.958	.980	.987	.991	1.842	1.075	.837	1.850
26	3.20	6.5	e.—	.887	1.720	v.g.+	.561	.723	.814	.856	.897	.948	.964	.977	.980	.986	1.859	1.087	.815	1.872
27	3.4	6.4	e.	.883	1.739	g.	.590	.706	.784	.827	.865	.930	.953	.965	.971	.980	1.902	1.101	.803	1.915
28	3.79	6.7	v.g.—	.895	1.683	e.—	.589	.727	.810	.861	.885	.943	.961	.975	.978	.979	1.818	1.088	.822	1.831
31	5.38	10.0	v.g.+	.897	1.634	v.g.	.602	.744	.816	.855	.885	.936	.960	.980	.988	.994	1.849	1.143	.784	1.869
Nov. 3	4.93	3.6	e.(?)	.916	1.650	p.	.629	.751	.825	.875	.905	.946	.967	.985	.985	.990	1.809	1.100	.832	1.816
4	6.88	5.0	g.+	.904	1.708	e.+	.600	.730	.810	.861	.902	.952	.965	.979	.983	.989	1.843	1.085	.833	1.853
5	6.01	3.3	g.	.893	1.707	e.+	.592	.720	.799	.845	.886	.937	.954	.975	.984	.995	1.812	1.064	.839	1.818
7	4.52	6.0	g.	.906	1.701	v.g.+	.605	.727	.812	.864	.902	.946	.966	.979	.983	.994	1.877	1.110	.816	1.889
8	3.61	5.6	e.	.906	1.720	e.	.613	.740	.815	.859	.896	.934	.954	.976	.980	.981	1.892	1.106	.819	1.903
9	4.70	10.0	v.g.—	.879	1.723	v.g.—	.575	.710	.893	.845	.881	.930	.946	.966	.971	.977	1.899	1.113	.789	1.919

TABLE 33.—*Solar-constant values, Mount Wilson, 1914.*

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry. Grade.	Pyrheliometry. Apparent atmospheric transmission a.	Pyrheliometry. Apparent solar constant A_o.	Bolometry. Grade.	Atmospheric transmission for different wave lengths. μ 0.35	μ 0.40	μ 0.45	μ 0.50	μ 0.60	μ 0.70	μ 0.80	μ 1.00	μ 1.20	μ 1.60	Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.
	mm.	*mm.*																		
June 12	1.52	7.7	v.g.	0.883	1.808	g.+	0.622	0.738	0.811	0.850	0.868	0.934	0.953	0.963	0.965	0.967	1.963	1.093	0.807	1.979
13	4.15	7.7	v.g.+	.895	1.764	e.—	.618	.734	.800	.843	.870	.927	.961	.981	.986	.990	1.929	1.102	.812	1.945
14	3.23	8.3	v.g.+	.895	1.744	e.—	.583	.725	.810	.858	.882	.925	.955	.968	.970	.973	1.929	1.116	.802	1.946
15	2.99	6.9	e.	.887	1.797	e.+	.550	.704	.806	.859	.879	.930	.953	.966	.969	.968	1.966	1.101	.805	1.980
16	5.98	9.6	e.	.885	1.717	e.	.538	.694	.785	.829	.865	.920	.939	.961	.969	.977	1.920	1.129	.784	1.940
19	3.75	11.5	v.g.	.887	1.728	v.g.	.570	.722	.811	.855	.895	.943	.960	.967	.968	.969	1.895	1.110	.799	1.918
20	7.54	16.4	g.	.883	1.683	e.—	.535	.681	.762	.818	.855	.920	.944	.964	.972	.979	1.924	1.163	.760	1.958
21	5.32	8.3	e.—	.904	1.729	e.	.583	.733	.815	.848	.889	.954	.969	.982	.988	.991	1.902	1.110	.814	1.919
22	4.75	9.2	v.g.+	.887	1.779	e.—	.547	.712	.810	.845	.870	.931	.951	.966	.968	.970	1.958	1.111	.798	1.977
23	4.54	5.3	v.g.	.904	1.736	e.+	.542	.710	.805	.845	.884	.935	.961	.974	.981	.983	1.933	1.119	.807	1.944
24	4.96	7.9	e.—	.895	1.760	v.g.—	.559	.730	.816	.836	.863	.933	.964	.981	.985	.994	1.921	1.106	.809	1.937
25	5.98	9.5	v.g.+	.879	1.808	v.g.	.559	.724	.818	.856	.880	.930	.953	.971	.970	.975	1.940	1.082	.811	1.959
26	2.98	3.5	e.—	.902	1.808	e.	.620	.737	.810	.847	.875	.934	.958	.975	.981	.986	1.960	1.088	.828	1.958
30	5.71	18.5	v.g.+	.869	1.688	v.g.+	.490	.655	.746	.807	.845	.897	.932	.970	.981	.988	1.946	1.176	.739	1.985
July 1	4.92	10.1	e.—	.889	1.755	e.	.546	.704	.804	.856	.876	.939	.958	.972	.981	.989	1.953	1.124	.791	1.974
2	4.01	9.8	v.g.	.893	1.727	e.—	.545	.695	.800	.838	.870	.935	.961	.975	.982	.987	1.929	1.128	.792	1.949
17	8.50	15.4	e.	.897	1.710	e.	.560	.722	.822	.859	.879	.940	.960	.979	.981	.982	1.903	1.131	.793	1.935
18	7.67	17.1	e.	.887	1.678	e.	.554	.714	.812	.856	.877	.931	.954	.970	.975	.977	1.873	1.136	.781	1.908
19	7.81	21.4	v.g.—	.873	1.666	v.g.+	.555	.695	.786	.831	.870	.924	.940	.953	.957	.965	1.912	1.180	.740	1.967
20	8.06	18.2	v.g.	.879	1.694	v.g.—	.572	.708	.791	.841	.871	.932	.953	.968	.968	.970	1.915	1.152	.763	1.953
21	6.59	18.2	g.+	.883	1.722	e.	.604	.728	.799	.851	.871	.928	.946	.963	.967	.977	1.934	1.145	.771	1.972
22	6.54	12.6	v.g.	.881	1.764	e.+	.578	.720	.811	.859	.885	.932	.952	.970	.972	.982	1.926	1.106	.797	1.952
23	5.69	10.9	e.	.871	1.792	v.g.+	.560	.695	.780	.828	.866	.920	.944	.957	.959	.965	1.983	1.118	.778	2.006
26	5.85	17.4	v.g.—	.891	1.704	v.g.+	.630	.755	.826	.870	.892	.942	.962	.972	.973	.979	1.902	1.137	.783	1.938
27	6.97	8.3	g.	.902	1.740	e.	.575	.720	.802	.855	.895	.946	.968	.976	.978	.983	1.932	1.119	.805	1.949
28	2.51	4.5	e.	.902	1.804	v.g.+	.603	.728	.800	.855	.891	.944	.969	.982	.982	.985	1.959	1.091	.826	1.969
29	2.37	7.5	e.	.904	1.747	v.g.—	.580	.744	.838	.882	.903	.950	.970	.984	.987	.987	1.907	1.100	.822	1.922
30	5.14	18.2	e.	.869	1.750	v.g.—	.534	.684	.785	.846	.884	.923	.937	.944	.948	.953	1.996	1.162	.747	2.035
Aug. 1	6.71	23.6	v.g.	.843	1.766	v.g.+	.500	.651	.749	.807	.843	.896	.925	.954	.958	.957	2.016	1.171	.720	2.069
2	6.78	20.9	v.g.	.881	1.733	e.	.575	.725	.814	.862	.886	.941	.958	.968	.971	.969	1.928	1.138	.774	1.972
5	6.84	24.9	g.+	.800	1.834	e.	.462	.611	.700	.756	.800	.869	.890	.905	.915	.925	2.060	1.153	.693	2.117
7	8.37	24.0	g.+	.863	1.715	v.g.	.527	.674	.765	.821	.853	.916	.944	.959	.965	.971	1.954	1.168	.738	2.006
8	9.47	16.6	v.g.+	.893	1.698	v.g.+	.587	.735	.820	.854	.885	.942	.960	.971	.980	.990	1.914	1.146	.779	1.948
9	4.50	12.5	v.g.+	.893	1.750	e.—	.613	.733	.812	.849	.892	.943	.961	.977	.981	.985	1.962	1.136	.786	1.988
10	5.74	13.3	e.—	.891	1.733	e.	.612	.737	.817	.854	.891	.945	.963	.981	.983	.987	1.924	1.126	.791	1.952
11	4.63	14.9	e.	.879	1.756	e.+	.572	.718	.801	.850	.878	.927	.952	.965	.969	.974	1.959	1.133	.775	1.991
12	5.25	11.8	p.	.885	1.772	e.—	.582	.728	.824	.872	.890	.942	.956	.968	.974	.980	1.940	1.108	.798	1.964
14	9.66	22.8	v.g.	.859	1.699	v.g.+	.551	.683	.771	.827	.860	.913	.934	.952	.965	.977	1.910	1.151	.745	1.958
17	7.52	20.1	v.g.—	.855	1.678	e.—	.489	.650	.747	.807	.848	.912	.945	.968	.975	.979	1.887	1.149	.744	1.929
18	5.25	6.7	v.g.	.914	1.724	v.g.	.564	.734	.834	.875	.909	.962	.975	.983	.990	.990	1.924	1.123	.813	1.937
19	2.88	4.5	e.—	.906	1.776	e.—	.587	.747	.844	.880	.908	.951	.967	.979	.984	.984	1.926	1.089	.831	1.935
20	3.19	7.4	p.	.914	1.725	g.	.572	.750	.842	.896	.917	.950	.970	.979	.984	.984	1.954	1.141	.801	1.969
21	3.32	4.5	v.g.	.902	1.782	e.+	.585	.739	.824	.869	.897	.950	.965	.971	.974	.974	1.938	1.092	.825	1.947
22	2.63	3.7	e.	.910	1.773	e.	.578	.738	.830	.874	.907	.950	.965	.974	.976	.983	1.936	1.097	.829	1.945
23	6.15	7.6	e.	.875	1.823	e.+	.570	.703	.792	.843	.875	.935	.952	.966	.970	.975	1.960	1.083	.807	1.976
24	2.27	11.5	e.	.902	1.728	g.—	.591	.738	.832	.885	.916	.950	.956	.964	.965	.968	1.907	1.116	.807	1.930
26	5.27	10.3	e.	.902	1.750	e.	.586	.749	.838	.865	.911	.969	.975	.980	.982	.989	1.915	1.106	.815	1.936
27	6.00	6.8	v.g.—	.897	1.774	v.g.+	.577	.743	.834	.875	.913	.949	.965	.968	.971	.974	1.938	1.100	.815	1.952
28	5.39	7.5	v.g.+	.895	1.765	e.	.577	.738	.826	.870	.894	.948	.970	.980	.980	.986	1.926	1.099	.814	1.941
29	5.37	7.9	e.—	.914	1.594	e.+	.582	.749	.842	.890	.914	.952	.978	.991	.992	.995	1.765	1.116	.818	1.780
30	6.01	10.0	v.g.—	.826	1.788	v.g.+	.485	.630	.715	.765	.791	.840	.894	.936	.953	.970	2.038	1.151	.717	2.060
31	5.65	8.7	e.—	.867	1.799	e.	.545	.687	.769	.820	.861	.912	.934	.959	.965	.974	1.970	1.105	.784	1.988

TABLE 33.—*Solar-constant values, Mount Wilson, 1914*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry. Grade.	Apparent atmospheric transmission a.	Apparent solar constant A_o.	Bolometry. Grade.	Atmospheric transmission for different wave lengths. 0.35 μ	0.40 μ	0.45 μ	0.50 μ	0.60 μ	0.70 μ	0.80 μ	1.00 μ	1.20 μ	1.60 μ	Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.
	mm.	*mm.*																		
Sept. 1	5.29	10.0	e.	0.881	1.731	e.	0.595	0.733	0.810	0.855	0.874	0.935	0.961	0.981	0.983	0.992	1.897	1.107	0.795	1.917
2	4.02	6.1	v.g.	.881	1.801	e.	.583	.725	.817	.841	.883	.938	.958	.975	.980	.979	1.936	1.081	.814	1.948
3	3.69	11.4	e.	.900	1.744	e.	.634	.756	.825	.873	.898	.955	.974	.985	.988	.989	1.921	1.114	.807	1.944
4	5.64	19.1	v.g.	.895	1.715	e.+	.610	.740	.837	.886	.917	.953	.965	.975	.977	.982	1.913	1.138	.786	1.953
6	4.23	10.9	e.−	.904	1.727	e.+	.618	.749	.826	.876	.908	.956	.973	.986	.988	.992	1.902	1.113	.811	1.924
7	3.53	3.5	v.g.+	.910	1.770	g.−	.618	.755	.845	.875	.901	.948	.970	.979	.980	.981	1.937	1.097	.829	1.944
8	4.03	10.9	v.g.	.908	1.719	e.−	.619	.735	.810	.858	.890	.947	.965	.974	.976	.982	1.939	1.140	.796	1.961
9	6.99	7.6	e.	.895	1.766	v.g.	.595	.724	.805	.860	.900	.957	.971	.983	.988	.990	1.918	1.095	.818	1.984
10	4.01	13.5	e.	.893	1.724	e.−	.590	.726	.806	.858	.890	.955	.963	.968	.971	.978	1.929	1.135	.787	1.957
11	3.22	12.4	g.+	.904	1.701	v.g.	.582	.739	.830	.881	.916	.953	.965	.973	.979	.986	1.921	1.144	.790	1.946
12	2.71	5.8	e.+	.918	1.704	v.g.	.587	.740	.826	.876	.915	.949	.962	.975	.978	.988	1.928	1.138	.806	1.940
13	5.34	7.6	e.−	.902	1.715	e.+	.588	.740	.827	.862	.886	.947	.965	.979	.984	.990	1.908	1.120	.804	1.923
14	6.39	9.7	g.+	.883	1.799	e.	.586	.723	.810	.875	.897	.945	.966	.980	.982	.985	1.936	1.086	.812	1.956
15	3.54	10.6	v.g.+	.887	1.771	e.−	.591	.738	.818	.855	.888	.937	.957	.971	.973	.976	1.946	1.110	.798	1.968
16	5.18	7.9	v.g.	.897	1.760	e.+	.580	.725	.810	.864	.900	.945	.967	.979	.983	.983	1.936	1.108	.808	1.952
19	1.07	17.9	v.g.+	.902	1.701	e.+	.614	.747	.832	.839	.915	.960	.979	.985	.985	.985	1.888	1.131	.797	1.925
20	7.32	5.7	e.	.916	1.728	e.	.594	.786	.825	.881	.901	.955	.975	.986	.983	.990	1.925	1.120	.818	1.936
21	4.44	8.0	e.[3]	.906	1.761	e.[3]	.605	.740	.826	.879	.900	.946	.966	.979	.985	.986	1.915	1.113	.814	1.960
22	7.75	10.6	v.g.−	.908	1.714	v.g.+	.600	.733	.825	.884	.912	.962	.980	.985	.990	.992	1.897	1.118	.812	1.918
23	8.28	14.0	v.g.−	.885	1.772	e.	.597	.726	.807	.857	.890	.932	.957	.968	.975	.982	1.959	1.122	.789	1.989
28	5.81	14.0	v.g.	.897	1.685	e.+	.595	.723	.808	.859	.892	.942	.965	.980	.983	.987	1.915	1.153	.778	1.944
Oct. 2	6.80	6.6	e.	.902	1.762	g.−	.625	.738	.815	.855	.895	.945	.972	.988	.990	.990	1.943	1.110	.812	1.957
4	7.12	13.3	v.g.+	.887	1.674	e.?	.569	.713	.800	.850	.885	.929	.954	.962	.966	.970	1.914	1.159	.765	1.941
9	5.15	13.5	v.g.	.906	1.706	e.	.637	.750	.824	.870	.907	.954	.964	.979	.981	.988	1.922	1.142	.792	1.950
10	4.28	5.8	v.g.−	.908	1.742	g.	.590	.720	.812	.865	.901	.952	.965	.975	.981	.988	1.950	1.125	.806	1.962
11	6.02	9.5	g.−	.908	1.708	e.	.598	.725	.812	.870	.893	.950	.972	.983	.985	.985	1.922	1.136	.799	1.941
12	3.80	9.2	e.−	.904	1.746	v.g.+	.592	.735	.821	.870	.905	.959	.974	.983	.984	.984	1.934	1.118	.808	1.953
13	3.08	6.8	e.	.906	1.758	e.+	.592	.732	.820	.869	.903	.950	.970	.980	.983	.987	1.933	1.106	.818	1.947
14	3.09	7.3	e.−	.914	1.709	v.g.	.593	.736	.824	.877	.915	.960	.977	.984	.986	.987	1.920	1.132	.808	1.935
15	3.75	11.3	e.	.895	1.736	v.g.+	.588	.731	.810	.866	.911	.954	.969	.975	.976	.974	1.934	1.126	.794	1.957
16	3.88	10.8	e.	.906	1.653	v.g.	.591	.723	.811	.853	.890	.947	.968	.978	.984	.984	1.926	1.178	.768	1.948
18	5.50	13.7	e.	.904	1.723	e.−	.638	.798	.825	.872	.906	.953	.966	.983	.986	.992	1.934	1.138	.793	1.963
19	5.02	12.3	v.g.	.900	1.752	e.	.628	.752	.823	.872	.913	.960	.978	.986	.987	.985	1.926	1.113	.808	1.951
20	6.67	16.1	v.g.+	.897	1.727	e.+	.645	.760	.826	.874	.912	.955	.970	.982	.985	.986	1.925	1.133	.791	1.959

TABLE 34.—*Solar-constant values, Mount Wilson, 1915.*

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry.			Bolometry.											Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.
			Grade.	Apparent atmospheric transmission a.	Apparent solar constant A_o.	Grade.	Atmospheric transmission for different wave lengths.													
							μ 0.35	μ 0.40	μ 0.45	μ 0.50	μ 0.60	μ 0.70	μ 0.80	μ 1.00	μ 1.20	μ 1.60				
	mm.	*mm.*																		
June 8	5.89	16.8	v. g.—	0.877	1.724	e.	0.562	0.705	0.802	0.852	0.882	0.950	0.973	0.989	0.992	0.987	1.899	1.121	0.782	1.934
10	4.66	6.2	e.	.904	1.765	e.	.580	.726	.821	.878	.904	.952	.975	.984	.986	.988	1.932	1.101	.820	1.945
11	3.80	4.8	e.—	.903	1.781	e.	.598	.734	.812	.869	.898	.952	.970	.979	.982	.982	1.916	1.081	.833	1.926
12	2.35	4.5	e.—	.912	1.728	e.	.605	.735	.809	.864	.901	.957	.980	.994	.995	.994	1.894	1.101	.828	1.903
13	3.58	3.0	v. g.	.921	1.739	e.—	.634	.750	.826	.878	.903	.955	.982	.987	.989	.992	1.903	1.097	.839	1.909
16	4.28	14.5	v. g.—	.918	1.642	g.	.612	.740	.820	.883	.915	.973	.982	.990	.993	.995	1.874	1.157	.792	1.903
18	3.40	7.6	v. g.—	.902	1.781	v. g.	.598	.740	.819	.877	.901	.952	.975	.981	.985	.982	1.955	1.106	.814	1.971
19	3.58	6.8	v. g.	.897	1.792	g.+	.606	.751	.830	.879	.909	.960	.981	.988	.988	.985	1.908	1.072	.836	1.922
22	4.56	5.9	v. g.	.910	1.743	e.—	.620	.759	.835	.880	.897	.960	.976	.986	.991	.993	1.890	1.091	.833	1.902
24	4.34	6.0	v. g.+	.852	1.894	e.—	.583	.693	.772	.817	.857	.900	.932	.959	.961	.959	1.998	1.061	.802	2.011
25	5.08	3.5	v. g.—	.858	1.926	e.	.575	.708	.787	.825	.856	.922	.949	.960	.961	.966	1.992	1.038	.826	2.000
26	3.98	6.9	v. g.+	.889	1.784	e.	.592	.734	.805	.858	.892	.944	.962	.971	.976	.980	1.922	1.085	.819	1.936
27	5.65	8.6	e.	.864	1.775	e.—	.565	.695	.780	.820	.850	.916	.944	.954	.959	.966	1.934	1.098	.786	1.951
28	3.36	4.8	e.—	.875	1.852	e.—	.572	.715	.800	.850	.877	.922	.947	.961	.969	.971	1.970	1.068	.819	1.980
July 3	6.39	18.3	e.—	.894	1.685	e.—	.590	.728	.817	.870	.895	.942	.972	.984	.987	.988	1.878	1.136	.787	1.915
4	7.20	8.0	g.	.885	1.807	e.—	.570	.723	.817	.867	.885	.938	.964	.977	.980	.985	1.934	1.079	.821	1.950
5	3.85	4.9	e.—	.896	1.783	e.	.587	.731	.823	.862	.897	.950	.967	.976	.977	.986	1.920	1.082	.828	1.930
6	3.22	7.6	e.[2]	.891	1.782	e.	.576	.715	.802	.850	.886	.939	.957	.973	.977	.982	1.961	1.108	.803	1.977
7	5.12	21.9	e.+	.884	1.736	e.+	.618	.744	.823	.868	.900	.948	.962	.969	.970	.975	1.922	1.132	.780	1.968
8	5.56	21.2	v. g.+	.888	1.728	e.	.590	.741	.830	.869	.903	.954	.970	.982	.985	.985	1.910	1.131	.785	1.955
9	7.03	15.6	v. g.+	.887	1.744	e.	.607	.743	.830	.875	.901	.946	.967	.982	.987	.992	1.902	1.108	.800	1.934
10	8.93	14.8	e.—	.895	1.728	e.	.580	.725	.820	.870	.902	.963	.980	.990	.990	.989	1.898	1.116	.802	1.929
11	4.61	11.7	e.—	.897	1.757	e.	.598	.739	.820	.872	.901	.955	.971	.984	.986	.986	1.923	1.108	.809	1.947
12	2.89	12.4	v. g.	.891	1.784	v. g.	.610	.740	.816	.867	.907	.965	.975	.982	.986	.990	1.922	1.091	.817	1.947
13	4.60	11.4	v. g.—	.881	1.881	g.	.598	.740	.817	.858	.885	.945	.965	.970	.974	.980	1.936	1.041	.846	1.959
14	3.95	8.6	e.—	.895	1.800	v. g.+	.615	.755	.830	.876	.903	.963	.978	.985	.986	.992	1.932	1.082	.826	1.949
15	3.67	4.2	e.	.891	1.850	e.	.600	.733	.809	.859	.890	.948	.965	.978	.981	.985	1.967	1.068	.834	1.976
16	4.13	5.5	e.+	.901	1.786	e.	.585	.719	.807	.866	.908	.952	.970	.984	.987	.990	1.964	1.106	.814	1.976
17	2.95	3.6	e.	.906	1.820	e.	.569	.715	.815	.877	.907	.951	.969	.981	.982	.982	1.972	1.086	.832	1.979
18	3.14	10.2	e.—	.909	1.747	v. g.	.595	.742	.832	.876	.907	.950	.971	.983	.984	.989	1.939	1.121	.810	1.960
26	3.88	7.9	v. g.—	.904	1.760	e.—	.580	.740	.824	.873	.902	.955	.969	.982	.986	.990	1.934	1.107	.816	1.950
27	2.47	4.1	e.—	.906	1.796	e.	.599	.740	.825	.869	.899	.955	.974	.989	.989	.993	1.934	1.081	.838	1.943
28	2.20	3.5	v. g.+	.908	1.786	v. g.+	.608	.742	.822	.866	.905	.951	.968	.980	.983	.989	1.929	1.083	.838	1.936
29	5.63	7.0	e.	.900	1.753	e.	.581	.733	.826	.874	.895	.950	.974	.984	.984	.985	1.920	1.103	.816	1.934
30	6.54	9.3	e.—	.906	1.707	v. g.+	.582	.740	.831	.874	.897	.943	.968	.984	.985	.985	1.903	1.125	.804	1.922
31	5.38	6.9	e.	.907	1.716	v. g.	.615	.750	.829	.873	.898	.948	.960	.975	.979	.981	1.892	1.110	.816	1.906
Aug. 1	5.12	7.7	e.	.887	1.762	v. g.+	.575	.714	.800	.851	.883	.938	.955	.981	.981	.983	1.938	1.108	.800	1.954
2	5.26	9.1	e.	.905	1.708	e.+	.561	.723	.814	.866	.900	.954	.981	.992	.995	.990	1.899	1.122	.807	1.917
3	3.36	7.0	v. g.—	.903	1.762	e.—	.562	.731	.828	.874	.904	.950	.959	.984	.985	.986	1.932	1.103	.818	1.946
6	4.77	9.4	v. g.	.905	1.748	v. g.+	.633	.760	.829	.875	.901	.952	.975	.981	.985	.986	1.925	1.112	.814	1.944
7	3.53	6.4	v. g.+	.904	1.778	e.+	.599	.743	.825	.875	.900	.956	.974	.986	.988	.991	1.938	1.096	.824	1.951
8	4.57	6.4	v. g.	.902	1.801	e.	.590	.733	.819	.872	.903	.949	.966	.982	.985	.992	1.963	1.096	.822	1.976
9	3.62	6.1	e.—	.905	1.795	e.+	.578	.738	.825	.869	.901	.952	.971	.981	.986	.990	1.950	1.093	.828	1.963
10	2.39	4.3	v. g.	.907	1.798	e.—	.606	.755	.830	.880	.904	.958	.973	.982	.983	.988	1.937	1.082	.838	1.946
11	1.99	10.2	g.	.866	1.818	v. g.	.548	.692	.776	.832	.862	.930	.950	.969	.973	.982	1.975	1.098	.788	1.997
12	3.97	4.3	e.	.910	1.788	v. g.+	.619	.755	.835	.876	.907	.955	.971	.981	.985	.989	1.940	1.090	.835	1.949
13	4.35	4.9	v. g.—.	.895	1.833	e.+	.594	.739	.826	.875	.901	.953	.971	.986	.988	.985	1.940	1.063	.841	1.950
14	5.10	6.3	e.—	.895	1.824	v. g.+	.576	.720	.804	.857	.896	.950	.964	.974	.977	.978	1.963	1.083	.826	1.976
15	3.41	6.2	e.—	.894	1.822	v. g.	.596	.750	.825	.875	.898	.945	.962	.978	.980	.983	1.952	1.078	.829	1.965
16	1.87	4.5	e.—	.895	1.835	v. g.	.586	.738	.825	.869	.901	.953	.970	.978	.978	.980	1.958	1.072	.834	1.968
17	2.90	5.3	v. g.	.914	1.686	e.+	.617	.756	.837	.880	.912	.967	.975	.983	.984	.989	1.934	1.152	.792	1.945
18	1.95	19.5	e.	.908	1.777	e.	.607	.745	.829	.880	.915	.962	.975	.983	.984	.988	1.936	1.112	.816	1.977
19	2.16	7.3	e.	.911	1.756	v. g.	.612	.749	.830	.881	.914	.962	.977	.980	.982	.982	1.918	1.100	.827	1.933
20	3.00	13.8	g.	.902	1.660	g.	.584	.728	.804	.854	.890	.937	.960	.974	.980	.984	1.893	1.157	.779	1.921
21	4.43	9.2	p.	.902	1.694	v. g.+	.574	.716	.803	.857	.888	.938	.960	.972	.975	.982	1.914	1.140	.791	1.932

TABLE 34.—*Solar-constant values, Mount Wilson, 1915*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry. Grade.	Pyrheliometry. Apparent atmospheric transmission *a*.	Pyrheliometry. Apparent solar constant A_o.	Bolometry. Grade.	Atmospheric transmission for different wave lengths. 0.35μ	0.40μ	0.45μ	0.50μ	0.60μ	0.70μ	0.80μ	1.00μ	1.20μ	1.60μ	Solar constant E_o.	Ratio $\frac{E'}{A_o}$.	Atmospheric transmission $A_o\frac{a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.
	mm.	*mm.*																		
Aug. 22	4.78	6.6	v.g.	0.904	1.782	e.+	0.592	0.733	0.822	0.867	0.905	0.956	0.979	0.990	0.991	0.993	1.932	1.091	0.828	1.946
23	6.35	8.2	g.+	.879	1.785	v.g.−	.564	.694	.787	.843	.875	.925	.946	.961	.970	.976	1.984	1.120	.784	2.001
24	4.66	5.9	e.	.905	1.768	e.−	.582	.721	.805	.860	.894	.949	.967	.980	.983	.991	1.944	1.106	.818	1.956
25	2.38	2.8	e.−	.910	1.817	g.+	.603	.732	.821	.875	.911	.953	.974	.984	.985	.987	1.954	1.078	.843	1.960
27	10.39	24.5	g.	.881	1.607	v.g.−	.567	.706	.790	.845	.882	.935	.955	.968	.971	.978	1.853	1.183	.744	1.903
28	10.25	26.2	v.g.−	.867	1.711	v.g.−	.546	.681	.765	.823	.877	.942	.959	.974	.976	.985	1.930	1.160	.747	1.986
29	8.55	22.0	v.g.	.889	1.620	v.g.+	.544	.690	.779	.830	.880	.932	.956	.984	.988	.993	1.877	1.186	.749	1.923
31	8.16	19.8	v.g.	.865	1.672	v.g.+	.544	.690	.769	.825	.866	.925	.948	.966	.972	.977	1.854	1.132	.763	1.894
Sept. 3	7.37	19.6	e.−	.855	1.724	v.g.+	.536	.671	.750	.806	.852	.915	.940	.913	.965	.970	1.934	1.146	.746	1.976
4	5.26	13.2	g.	.869	1.779	v.g.−	.580	.714	.789	.833	.880	.935	.958	.973	.981	.984	1.921	1.095	.793	1.948
5	6.46	15.1	e.−	.879	1.708	v.g.	.572	.700	.781	.840	.880	.937	.958	.970	.975	.982	1.913	1.138	.772	1.945
6	7.88	14.4	e.−	.877	1.784	e.+	.541	.695	.784	.835	.874	.932	.950	.967	.970	.975	1.960	1.115	.786	1.990
7	6.65	6.9	v.g.	.879	1.833	e.	.572	.709	.785	.835	.883	.931	.956	.970	.975	.984	1.968	1.081	.813	1.983
8	5.20	4.3	e.	.910	1.772	g.+	.601	.743	.825	.873	.902	.960	.971	.978	.981	.985	1.920	1.088	.836	1.929
12	3.84	3.8	e.−	.906	1.799	v.g.(?)	.618	.750	.824	.870	.915	.964	.977	.987	.989	.993	1.934	1.079	.839	1.942
15	4.19	10.1	e.−	.879	1.776	v.g.	.549	.693	.787	.845	.873	.936	.955	.971	.975	.977	1.949	1.108	.793	1.970
16	4.11	13.2	e.	.862	1.780	g.	.510	.670	.760	.813	.856	.915	.940	.961	.968	.975	2.000	1.138	.756	2.028
17	4.91	12.1	e.	.875	1.794	e.−	.574	.710	.786	.840	.881	.935	.968	.973	.979	.980	1.966	1.109	.788	1.991
18	5.11	9.0	e.−	.894	1.787	e.	.556	.705	.794	.849	.883	.935	.960	.975	.981	.988	2.002	1.131	.790	2.021
19	4.90	7.3	e.	.906	1.758	e.−	.618	.746	.816	.864	.907	.950	.971	.982	.985	.994	1.942	1.112	.814	1.957
20	5.72	15.2	e.−	.894	1.732	e.	.580	.720	.801	.858	.894	.949	.971	.985	.986	.989	1.944	1.141	.784	1.976
22	5.55	15.8	e.−	.900	1.743	v.g.	.597	.750	.837	.885	.915	.959	.972	.984	.986	.989	1.942	1.133	.795	1.975
23	3.41	5.5	e.	.908	1.799	e.−	.592	.748	.830	.880	.908	.961	.979	.983	.984	.988	1.937	1.082	.838	1.948
27	5.70	4.3	e.	.897	1.788	v.g.	.611	.745	.821	.870	.906	.956	.975	.986	.987	.990	1.912	1.073	.835	1.921
28	3.91	5.5	e.−	.910	1.749	v.g.+	.593	.736	.816	.876	.905	.958	.975	.989	.992	.994	1.924	1.106	.823	1.935
29	4.21	9.0	e.	.888	1.756	v.g.+	.538	.695	.790	.839	.878	.939	.961	.978	.982	.986	1.947	1.118	.794	1.965
30	4.14	9.2	v.g.	.885	1.779	e.−	.575	.718	.798	.854	.882	.947	.962	.975	.978	.986	1.966	1.115	.793	1.985
Oct. 1	4.22	9.9	e.−	.885	1.793	e.	.575	.713	.797	.855	.844	.939	.962	.975	.979	.983	1.959	1.104	.802	1.980
2	4.57	4.8	g.	.920	1.725	v.g.	.581	.736	.824	.880	.916	.967	.988	.995	.996	.995	1.889	1.101	.835	1.899
3	4.64	8.0	v.g.	.893	1.738	p.	.543	.703	.795	.846	.878	.941	.968	.983	.983	.985	1.938	1.124	.794	1.954
4	2.64	6.4	v.g.	.884	1.828	v.g.	.560	.712	.802	.859	.890	.948	.970	.979	.979	.984	1.962	1.080	.818	1.975
5	2.90	4.1	e.	.915	1.764	v.g.−	.567	.718	.816	.875	.905	.959	.978	.989	.985	.989	1.948	1.108	.825	1.956
6	2.44	3.6	v.g.	.916	1.777	v.g.	.604	.735	.831	.875	.915	.964	.984	.991	.994	.998	1.937	1.094	.837	1.945
7	2.68	4.0	v.g.	.916	1.762	v.g.+	.616	.760	.835	.885	.914	.964	.978	.985	.985	.986	1.924	1.096	.835	1.932
8	3.81	4.7	v.g.	.881	1.891	g.+	.537	.700	.802	.861	.902	.950	.968	.982	.985	.984	2.042	1.085	.812	2.052
9	2.92	5.0	v.g.+	.906	1.807	v.g.+	.586	.736	.828	.880	.914	.951	.975	.990	.990	.988	1.957	1.088	.832	1.967
11	3.38	5.0	v.g.−	.935	1.662	p.	.607	.745	.830	.877	.907	.956	.972	.980	.983	.986	1.936	1.170	.798	1.946
12	2.94	6.4	v.g.(?)	.883	1.801	v.g.+	.602	.749	.828	.866	.905	.959	.970	.979	.985	.990	1.933	1.080	.817	1.946
13	3.93	10.0	e.+	.906	1.706	e.−	.600	.740	.830	.870	.900	.942	.963	.976	.983	.990	1.936	1.146	.790	1.957
14	4.81	10.8	e.−	.906	1.709	v.g.+	.596	.729	.821	.876	.905	.955	.974	.985	.988	.986	1.901	1.125	.805	1.923
15	4.65	9.4	e.	.907	1.677	v.g.−	.572	.722	.819	.866	.900	.953	.969	.980	.978	.985	1.878	1.131	.802	1.897
16	3.61	6.6	e.−	.909	1.735	v.g.+	.568	.719	.805	.865	.896	.950	.975	.989	.993	.993	1.932	1.120	.811	1.945
17	3.38	6.0	v.g.	.894	1.799	e.−	.596	.723	.800	.861	.905	.955	.976	.987	.990	.990	1.940	1.085	.824	1.952
18	4.02	5.7	v.g.	.895	1.810	e.−	.589	.729	.810	.858	.900	.958	.975	.987	.993	.990	1.942	1.079	.829	1.954
19	3.27	3.2	v.g.	(.915)	1.778	v.g.	.598	.739	.824	.878	.919	.965	.980	.990	.990	.992	1.938	1.093	.837	1.945
20	3.26	5.3	e.	.917	1.753	v.g.−	.605	.749	.831	.880	.922	.969	.982	.987	.986	.986	1.930	1.106	.828	1.941
21	2.88	3.8	e.	.908	1.792	e.+	.586	.740	.828	.884	.908	.957	.978	.986	.990	.994	1.942	1.087	.834	1.950
22	2.69	3.2	e.	.919	1.753	v.g.	.565	.733	.824	.888	.916	.961	.979	.992	.995	.994	1.925	1.101	.834	1.932

TABLE 35.—*Solar-constant values, Mount Wilson, 1916.*

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry.			Bolometry.												Solar constant E_0.	Ratio $\frac{E'_0}{A_0}$	Atmospheric transmission $\frac{A_0 a}{E'_0}$	Solar constant corrected for zero water vapor E'_0.
			Grade.	Apparent atmospheric transmission a.	Apparent solar constant A_0.	Grade.	Atmospheric transmission for different wave lengths. 0.35μ	0.40μ	0.45μ	0.50μ	0.60μ	0.70μ	0.80μ	1.00μ	1.20μ	1.60μ				
	mm.	mm.																		
June 16	5.33	.....	v. g.—	0.908	1.712	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
17	2.83	19.6	v. g.+	.891	1.662	v. g.+	0.600	0.735	0.809	0.859	0.882	0.942	0.965	0.976	0.982	0.985	1.903	1.148	0.776	1.944
19	5.98	5.3	e.	.887	1.746	e.—	.581	.722	.801	.842	.871	.923	.949	.964	.970	.974	1.929	1.111	.798	1.940
20	6.01	9.9	v. g.—	.900	1.741	v. g.	.585	.722	.806	.869	.913	.938	.963	.986	.989	.982	1.930	1.120	.803	1.950
22	4.82	5.5	e.	.891	1.767	e.—	.580	.724	.796	.845	.885	.937	.962	.981	.983	.991	1.936	1.101	.809	1.947
23	3.78	7.1	e.—	.869	1.840	v. g.+	.582	.720	.801	.850	.874	.930	.949	.957	.960	.963	1.974	1.080	.804	1.989
24	4.53	7.8	v. g.	.891	1.762	e.—	.595	.722	.789	.842	.887	.934	.957	.978	.982	.983	1.951	1.116	.798	1.967
25	5.35	13.7	v. g.+	.881	1.760	v. g.	.601	.745	.822	.870	.902	.942	.955	.963	.966	.969	1.909	1.100	.801	1.937
26	6.52	13.5	e.—	.883	1.738	v. g.—	.565	.734	.825	.876	.898	.950	.970	.980	.981	.980	1.920	1.089	.811	1.948
27	7.43	.....	v. g.	.885	1.764	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
30	4.75	12.6	v. g.	.889	1.760	v. g.—	.636	.743	.814	.870	.905	.950	.968	.979	.980	.981	1.889	1.088	.817	1.915
July 1	2.19	14.0	e.	.895	1.744	g.+	.630	.754	.825	.869	.902	.954	.968	.974	.975	.972	1.925	1.120	.799	1.954
2	3.96	8.1	e.—	.908	1.714	g.	.620	.747	.819	.863	.897	.942	.960	.975	.978	.982	1.914	1.126	.807	1.930
3	5.41	6.8	e.	.900	1.795	v. g.—	.615	.757	.826	.867	.900	.951	.973	.982	.983	.987	1.934	1.085	.829	1.948
4	2.87	5.8	e.	.902	1.793	v. g.+	.591	.748	.824	.867	.905	.955	.968	.972	.965	.985	1.942	1.090	.828	1.954
5	3.58	4.9	e.—	.906	1.787	e.—	.604	.756	.840	.878	.899	.954	.975	.986	.986	.983	1.935	1.088	.832	1.945
6	3.85	7.0	e.	.905	1.762	v. g.	.583	.736	.819	.871	.902	.958	.969	.975	.979	.984	1.937	1.107	.817	1.951
7	3.84	2.9	e.	.910	1.822	v. g.	.616	.743	.821	.867	.907	.960	.975	.981	.983	.983	1.936	1.065	.854	1.942
8	4.51	2.2	e.—	.912	1.818	e.—	.602	.747	.826	.884	.920	.965	.981	.985	.986	.989	1.938	1.068	.853	1.943
9	2.50	3.5	v. g.	.910	1.801	v. g.+	.630	.750	.826	.881	.903	.951	.973	.978	.982	.986	1.951	1.086	.837	1.958
10	4.99	9.2	v. g.	.891	1.692	g.+	.557	.707	.796	.848	.894	.940	.970	.985	.985	.986	1.860	1.110	.803	1.878
11	4.96	16.6	e.—	.877	1.700	v. g.—	.558	.722	.805	.840	.878	.939	.961	.978	.983	.984	1.881	1.126	.778	1.915
12	6.72	14.0	v. g.	.893	1.673	g.+	.585	.708	.792	.843	.884	.936	.960	.975	.975	.974	1.897	1.151	.776	1.926
15	6.63	9.2	g.+	.906	1.702	v. g.	.584	.723	.820	.860	.896	.945	.968	.980	.981	.986	1.895	1.124	.805	1.914
16	3.29	9.6	e.—	.855	1.884	g.	.595	.714	.782	.827	.857	.921	.936	.958	.963	.970	1.996	1.070	.800	2.016
17	3.49	5.5	v. g.	.909	1.762	e.—	.630	.746	.820	.865	.905	.952	.966	.976	.976	.974	1.929	1.101	.826	1.940
18	4.28	5.4	e.	.905	1.797	v. g.	.615	.750	.839	.880	.911	.951	.971	.983	.985	.985	1.921	1.075	.841	1.932
19	4.29	15.4	e.	.888	1.746	e.+	.592	.734	.800	.849	.887	.945	.962	.971	.973	.976	1.933	1.125	.789	1.965
22	7.81	24.6	e.—	.860	1.678	v. g.—	.545	.681	.785	.837	.864	.915	.935	.950	.953	.956	1.901	1.163	.739	1.953
23	9.04	24.9	e.—	.855	1.674	v. g.—	.519	.673	.757	.804	.835	.895	.925	.953	.960	.963	1.942	1.191	.718	1.995
24	7.17	20.1	e.—	.859	1.773	v. g.—	.530	.681	.766	.814	.857	.923	.948	.957	.963	.965	1.970	1.135	.756	2.013
25	9.43	7.2	v. g.+	.905	1.760	e.—	.618	.746	.825	.870	.899	.946	.968	.982	.987	.990	1.930	1.104	.819	1.944
28	9.36	4.0	v. g.+	.906	1.800	e.—	.596	.733	.824	.870	.907	.949	.970	.980	.983	.988	1.937	1.080	.838	1.945
29	7.66	4.7	v. g.+	.918	1.739	e.—	.650	.766	.829	.871	.906	.958	.970	.977	.983	.989	1.922	1.111	.826	1.932
30	6.96	6.3	e.—	.900	1.730	e.—	.632	.745	.820	.873	.897	.948	.969	.979	.982	.990	1.920	1.116	.805	1.932
31	8.70	17.3	v. g.—	.897	1.686	v. g.—	.613	.736	.808	.858	.886	.944	.964	.981	.982	.980	1.906	1.151	.779	1.942
Aug. 10	4.09	4.3	e.—	.818	1.825	g.+	.483	.601	.684	.737	.778	.840	.875	.914	.935	.949	2.000	1.100	.743	2.009
11	3.31	3.3	v. g.—	.845	1.793	g.	.510	.655	.727	.777	.816	.873	.905	.944	.955	.967	1.936	1.083	.780	1.943
12	5.59	4.2	v. g.—	.891	1.699	v. g.	.594	.716	.796	.847	.885	.935	.956	.975	.983	.983	1.871	1.106	.806	1.879
13	5.68	4.3	v. g.	.880	1.787	v. g.	.605	.722	.786	.835	.868	.926	.948	.962	.967	.974	1.954	1.098	.801	1.963
14	4.03	4.1	v. g.	.866	1.874	v. g.—	.570	.700	.773	.826	.854	.910	.934	.955	.969	.981	1.979	1.061	.816	1.988
15	5.62	5.9	v. g.—	.887	1.765	e.—	.591	.716	.789	.842	.867	.926	.943	.962	.969	.979	1.930	1.100	.806	1.942
16	6.21	5.8	e.	.893	1.749	e.+	.580	.718	.795	.850	.880	.929	.955	.969	.975	.979	1.924	1.106	.807	1.936
17	6.16	6.4	e.	.895	1.762	g.	.570	.714	.794	.846	.881	.931	.954	.973	.975	.984	1.999	1.141	.783	2.012
18	7.25	8.3	e.	.902	1.723	v. g.—	.580	.718	.805	.866	.892	.938	.965	.979	.977	.980	1.903	1.113	.809	1.920
19	5.43	6.5	e.	.894	1.764	v. g.	.595	.722	.802	.858	.884	.929	.955	.978	.977	.980	1.917	1.093	.817	1.930
20	4.02	3.3	e.—	.892	1.840	v. g.	.591	.721	.802	.853	.886	.935	.961	.973	.975	.982	1.947	1.061	.840	1.954
21	6.39	11.0	e.—	.882	1.761	g.	.587	.700	.783	.830	.867	.920	.943	.965	.970	.973	1.955	1.122	.785	1.978
22	6.72	10.1	e.	.891	1.797	v. g.	.592	.710	.784	.825	.880	.931	.955	.970	.972	.977	1.924	1.082	.823	1.945
25	11.94	23.6	p.	.840	1.763	p.	.565	.687	.761	.810	.844	.908	.933	.958	.967	.978	1.893	1.101	.762	1.942
27	11.69	25.5	e.—	.877	1.663	g.—	.574	.700	.782	.837	.872	.915	.939	.965	.975	.971	1.884	1.165	.752	1.937
28	12.01	23.3	v. g.+	.866	1.748	g.	.575	.707	.782	.835	.864	.915	.944	.961	.968	.974	1.959	1.148	.754	2.009
29	10.71	9.5	e.—	.902	1.720	g.+	.616	.738	.821	.863	.887	.939	.962	.969	.982	.990	1.892	1.110	.812	1.911
30	5.78	8.1	v. g.+	.886	1.767	g.	.617	.729	.788	.834	.875	.919	.949	.975	.980	.984	1.921	1.096	.808	1.937
31	3.55	5.0	e.	.896	1.812	e.—	.620	.745	.818	.874	.895	.941	.964	.979	.985	.985	1.937	1.074	.834	1.947

TABLE 35.—*Solar-constant values, Mount Wilson, 1916*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry. Grade.	Pyrheliometry. Apparent atmospheric transmission a.	Pyrheliometry. Apparent solar constant A_o.	Bolometry. Grade.	Atmospheric transmission for different wave lengths. 0.35μ	0.40μ	0.45μ	0.50μ	0.60μ	0.70μ	0.80μ	1.00μ	1.20μ	1.60μ	Solar constant E'_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.
	mm.	*mm.*																		
Sept. 1	3.12	5.6	e.—	0.907	1.757	v.g.+	0.585	0.734	0.821	0.869	0.899	0.945	0.966	0.978	0.980	0.983	1.918	1.098	.826	1.930
2	3.37	3.7	v.g.	.894	1.770	v.g.—	.581	.699	.780	.833	.871	.926	.949	.960	.969	.982	1.904	1.080	.828	1.911
3	7.25	3.9	e.	.869	1.756	p.	.580	.681	.741	.786	.833	.894	.924	.950	.956	.968	1.903	1.088	.799	1.911
4	3.32	3.4	v.g.—	.873	1.854	v.g.(?)	.598	.698	.762	.801	.853	.905	.930	.953	.962	.973	1.962	1.061	.822	1.969
5	3.20	3.8	v.g.	.897	1.728	v.g.	.592	.704	.779	.835	.865	.910	.941	.962	.970	.973	1.927	1.118	.801	1.935
6	5.76	4.3	v.g.+	.895	1.753	v.g.—	.610	.726	.801	.846	.870	.929	.953	.968	.974	.979	1.912	1.096	.817	1.921
7	4.14	3.5	e.	.891	1.816	g.	.576	.714	.800	.854	.890	.929	.951	.968	.973	.978	1.934	1.068	.833	1.941
8	3.91	10.9	g.+	.877	1.779	v.g.+	.587	.714	.790	.840	.879	.926	.945	.961	.970	.980	1.936	1.100	.797	1.958
9	1.79	4.3	e.+	.918	1.718	v.g.	.620	.738	.815	.867	.900	.945	.965	.980	.985	.993	1.898	1.109	.827	1.907
10	4.58	5.2	v.g.	.889	1.778	e.—	.605	.726	.799	.848	.874	.929	.953	.969	.975	.980	1.889	1.067	.832	1.899
11	2.74	8.5	v.g.	.876	1.790	e.—	.596	.711	.789	.843	.877	.923	.943	.960	.963	.971	1.938	1.091	.802	1.955
12	2.74	4.2	v.g.	.894	1.772	v.g.+	.600	.712	.800	.844	.882	.926	.954	.976	.986	.987	1.928	1.092	.818	1.937
13	1.66	4.0	v.g.+	.900	1.774	e.	.628	.740	.811	.868	.887	.939	.961	.975	.978	.980	1.915	1.084	.830	1.923
14	4.31	9.1	v.g.—	.898	1.736	e.	.603	.741	.825	.866	.886	.938	.957	.968	.973	.980	1.906	1.107	.810	1.924
15	3.98	12.8	v.g.	.882	1.724	g.+(?)	.525	.654	.750	.825	.870	.925	.939	.951	.959	.968	1.998	1.174	.751	2.025
16	5.71	13.3	v.g.	.871	1.744	v.g.	.515	.648	.739	.800	.850	.895	.929	.961	.965	.969	1.941	1.128	.771	1.969
17	4.10	11.8	e.	.882	1.688	g.	.565	.682	.758	.813	.860	.920	.947	.965	.971	.981	1.910	1.145	.769	1.934
18	4.69	15.7	e.	.844	1.786	v.g.	.491	.631	.722	.794	.823	.889	.925	.955	.959	.965	2.001	1.139	.740	2.035
23	5.45	10.1	v.g.—	.877	1.753	v.g.	.553	.695	.777	.847	.883	.932	.945	.958	.968	.984	1.915	1.103	.794	1.935
27	3.58	9.3	e.—	.898	1.733	e.—	.600	.729	.802	.850	.883	.940	.962	.978	.982	.984	1.916	1.116	.804	1.935
28	4.14	10.0	e.	.900	1.744	g.	.625	.740	.821	.876	.896	.945	.965	.979	.980	.980	1.909	1.105	.813	1.929
Oct. 5	4.64	10.5	e.	.900	1.685	p.	.598	.726	.795	.853	.896	.940	.964	.971	.975	.976	1.877	1.126	.799	1.898
8	4.89	11.7	v.g.	.893	1.660	e.	.576	.707	.799	.851	.877	.939	.969	.984	.985	.989	1.838	1.120	.796	1.861
12	5.64	12.0	e.	.866	1.746	v.g.	.525	.652	.729	.795	.844	.904	.928	.956	.964	.972	1.938	1.123	.770	1.963
14	5.68	10.3	v.g.+	.875	1.748	v.g.+	.550	.674	.751	.815	.863	.925	.946	.962	.971	.986	1.936	1.118	.781	1.957
15	4.97	8.5	v.g.—	.894	1.715	e.	.590	.719	.801	.852	.878	.936	.956	.966	.970	.978	1.908	1.122	.796	1.925
16	4.64	9.7	v.g.	.882	1.762	g.	.586	.713	.787	.848	.884	.930	.953	.968	.974	.977	1.915	1.098	.803	1.935
17	5.02	10.7	g.+	.879	1.790	v.g.	.596	.719	.801	.856	.882	.930	.956	.970	.975	.980	1.930	1.090	.806	1.952
18	4.29	4.6	e.	.906	1.780	e.—	.586	.719	.811	.874	.910	.948	.973	.987	.990	.990	1.924	1.086	.834	1.933
19	3.68	3.5	v.g.+	.904	1.804	e.—	.607	.735	.813	.870	.900	.949	.970	.979	.981	.979	1.948	1.084	.834	1.955
20	3.59	3.0	e.	.908	1.811	v.g.	.603	.720	.814	.867	.900	.948	.965	.975	.981	.983	1.963	1.086	.835	1.969
22	4.89	3.3	v.g.—	.893	1.840	g.	.588	.725	.805	.864	.890	.945	.963	.975	.981	.985	1.955	1.065	.838	1.962

TABLE 36.—*Solar-constant values, Mount Wilson, 1917.*

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry. Grade.	Pyrheliometry. Apparent atmospheric transmission a.	Pyrheliometry. Apparent solar constant A_o.	Bolometry. Grade.	Atmospheric transmission for different wave lengths. 0.35μ	0.40μ	0.45μ	0.50μ	0.60μ	0.70μ	0.80μ	1.00μ	1.20μ	1.60μ	Solar constant E'_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.
	mm.	*mm.*																		
July 1	1.57	15.1	e.	0.836	1.728	v.g.	0.451	0.602	0.692	0.755	0.799	0.870	0.905	0.931	0.943	0.956	2.001	1.176	0.710	2.034
2	8.98	18.3	v.g.	.809	1.685	g.	.392	.532	.631	.691	.752	.825	.870	.912	.930	.949	1.974	1.194	.677	2.013
3	8.39	17.8	v.g.+	.820	1.736	e.	.432	.581	.680	.746	.806	.869	.900	.935	.945	.958	1.950	1.145	.716	1.988
4	7.97	16.0	e.	.854	1.716	e.+	.495	.639	.730	.788	.827	.895	.925	.945	.949	.954	1.961	1.162	.734	1.995
5	7.04	15.9	e.	.882	1.744	e.	.560	.700	.790	.838	.885	.939	.959	.964	.968	.975	2.034	1.185	.744	2.069
6	9.38	16.4	e.	.879	1.764	e.—	.577	.711	.799	.850	.875	.928	.950	.966	.969	.975	1.954	1.126	.779	1.989
7	5.02	14.5	e.	.867	1.776	e.	.591	.705	.788	.837	.858	.921	.946	.960	.964	.974	1.950	1.115	.777	1.981

TABLE 36.—*Solar-constant values, Mount Wilson, 1917*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry.			Bolometry.											Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$.	Solar constant corrected for zero water vapor E'_o.
							Atmospheric transmission for different wave lengths.													
			Grade.	Apparent atmospheric transmission a.	Apparent solar constant A_o.	Grade.	μ 0.35	μ 0.40	μ 0.45	μ 0.50	μ 0.60	μ 0.70	μ 0.80	μ 1.00	μ 1.20	μ 1.60				
	mm.	*mm.*																		
July 8	1.70	3.8	v.g.+	0.901	1.820	e.+	0.615	0.731	0.819	0.875	0.896	0.944	0.969	0.979	0.980	0.984	1.930	1.064	0.846	1.938
9	1.86	4.6	v.g.+	.895	1.754	v.g.	.610	.728	.820	.875	.905	.950	.970	.985	.987	.990	1.912	1.095	.817	1.921
18	8.21	23.9	v.g.	.849	1.718	g.	.555	.684	.758	.815	.850	.906	.935	.950	.955	.963	1.923	1.148	.739	1.973
19	6.04	20.5	e.	.884	1.714	g.+	.606	.735	.811	.856	.882	.935	.948	.959	.962	.965	1.944	1.159	.762	1.988
29	12.00	27.5	g.	.859	1.755	g.	.587	.726	.819	.858	.888	.932	.947	.956	.960	.962	1.916	1.124	.764	1.974
Aug. 1	10.10	24.7	e.	.869	1.706	e.	.556	.690	.780	.835	.870	.917	.937	.950	.954	.959	1.952	1.174	.739	2.005
2	10.13	21.5	e.	.861	1.725	g.	.544	.685	.780	.828	.862	.915	.932	.954	.961	.967	1.955	1.160	.742	2.001
5	9.76	23.7	e.	.869	1.692	e.—	.522	.665	.760	.815	.858	.922	.942	.955	.962	.969	1.921	1.164	.746	1.971
6	7.94	17.3	e.	.879	1.696	e.—	.550	.690	.770	.819	.863	.920	.947	.961	.964	.971	1.932	1.160	.757	1.969
7	5.42	18.3	g.	.881	1.724	p.	.554	.688	.775	.840	.875	.940	.961	.977	(.979)	.976	1.866	1.103	.798	1.903
8	2.93	15.2	g.	.900	1.688	v.g.	.590	.728	.820	.870	.902	.954	.970	.979	.980	.983	1.874	1.127	.797	1.905
12	7.03	17.6	e.—	.867	1.706	p.	.570	.690	.765	.810	.840	.890	.920	.954	.958	.958	1.893	1.130	.767	1.929
13	6.62	14.2	p.	.857	1.672	p.	.474	.619	.708	.766	.816	.870	.906	.941	.952	.958	1.941	1.178	.727	1.971
14	7.86	19.7	e.	.813	1.672	v.g.	.457	.586	.665	.720	.775	.850	.889	.925	.937	.956	1.917	1.171	.694	1.958
16	5.48	12.9	e.—	.853	1.786	e.—	.518	.649	.745	.796	.838	.899	.931	.957	.963	.970	1.962	1.112	.766	1.989
17	5.73	4.2	v.g.	.906	1.753	e.—	.600	.732	.815	.869	.896	.935	.965	.982	.982	.988	1.933	1.107	.818	1.942
18	5.64	5.2	v.g.—	.888	1.818	v.g.	.618	.732	.800	.845	.877	.921	.945	.963	.972	.980	1.977	1.093	.812	1.988
19	6.48	5.5	e.	.893	1.747	e.—	.598	.717	.798	.846	.882	.931	.956	.972	.975	.980	1.913	1.101	.811	1.924
20	6.85	6.5	g.	.862	1.816	e.	.585	.700	.778	.825	.858	.906	.932	.955	.957	.963	1.943	1.070	.800	1.956
21	7.27	6.9	v.g.	.904	1.757	g.+	.665	.765	.830	.870	.890	.941	.965	.975	.981	.986	1.913	1.096	.824	1.927
22	5.45	9.5	v.g.	.893	1.771	e.	.600	.715	.811	.858	.885	.935	.957	.976	.980	.986	1.940	1.106	.806	1.960
26	8.61	14.4	e.	.900	1.714	e.	.583	.721	.804	.868	.893	.951	.970	.982	.981	.980	1.904	1.128	.798	1.934
27	5.41	10.9	v.g.	.904	1.753	v.g.	.654	.764	.834	.880	.908	.947	.963	.974	.972	.974	1.933	1.115	.811	1.955
28	5.99	7.2	v.g.+	.895	1.814	v.g.+	.635	.754	.829	.875	.896	.950	.970	.977	.976	.975	1.951	1.082	.826	1.966
29	10.1	3.2	v.g.+	.908	1.813	e.	.627	.748	.826	.875	.896	.945	.965	.975	.975	.977	1.958	1.082	.838	1.965
30	6.86	4.4	v.g.	.912	1.792	e.	.625	.745	.825	.869	.898	.953	.967	.975	.980	.982	1.961	1.099	.829	1.970
31	6.30	4.4	v.g.	.908	1.799	e.+	.615	.750	.828	.870	.900	.952	.975	.988	.988	.986	1.943	1.085	.837	1.952
Sept 1	2.34	7.8	v.g.	.902	1.757	v.g.—	.620	.742	.815	.856	.888	.943	.958	.969	.972	.975	1.944	1.115	.809	1.960
2	8.45	21.8	e.—	.865	1.662	g.—	.577	.681	.744	.792	.852	.909	.932	.954	.960	.967	1.876	1.156	.749	1.921
3	9.15	24.9	v.g.—	.855	1.756	g.+	.602	.703	.767	.816	.856	.918	.940	.953	.955	.962	1.936	1.132	.755	1.989
7	5.81	5.3	v.g.	.910	1.780	v.g.—	.655	.765	.835	.885	.913	.951	.965	.974	.974	.975	1.945	1.098	.828	1.956
8	1.98	5.2	v.g.	.900	1.812	e.	.660	.773	.836	.869	.894	.948	.968	.982	.983	.987	1.937	1.075	.837	1.948
9	2.76	5.6	v.g.—	.902	1.804	e.	.621	.745	.820	.865	.898	.950	.965	.977	.981	.980	1.969	1.097	.821	1.981
11	5.92	17.6	e.—	.900	1.745	v.g.	.625	.745	.825	.875	.900	.950	.968	.976	.979	.979	1.947	1.136	.792	1.984
12	5.38	12.2	e.	.897	1.748	v.g.	.638	.758	.830	.870	.899	.956	.970	.975	.979	.981	1.915	1.109	.809	1.940
13	3.10	7.5	v.g.	.891	1.832	v.g.—	.639	.756	.825	.860	.892	.947	.969	.975	.975	.980	1.927	1.060	.841	1.942
14	4.55	11.2	v.g.—	.895	1.762	e.—	.621	.742	.818	.862	.892	.940	.959	.968	.973	.976	1.956	1.122	.797	1.979
15	2.57	11.0	v.g.—	.889	1.777	v.g.+	.597	.731	.810	.855	.892	.945	.966	.975	.978	.982	1.944	1.106	.803	1.967
16	3.00	10.2	e.—	.897	1.764	e.	.592	.730	.806	.867	.902	.949	.966	.977	.978	.983	1.931	1.106	.810	1.952
17	2.34	8.6	v.g.—	.894	1.771	g.+	.606	.721	.815	.860	.892	.944	.960	.969	.974	.979	1.929	1.098	.813	1.946
18	3.64	12.6	v.g.—	.875	1.770	v.g.	.585	.705	.776	.828	.870	.917	.945	.958	.963	.965	1.937	1.108	.789	1.963
19	4.09	15.8	v.g.	.867	1.701	e.+	.525	.664	.746	.803	.855	.915	.942	.954	.960	.967	1.907	1.140	.760	1.940
20	4.94	17.4	e.	.872	1.679	g.	.561	.693	.767	.813	.852	.912	.945	.965	.969	.974	1.871	1.135	.768	1.906
22	4.34	9.1	v.g.—	.900	1.746	g.	.590	.730	.815	.860	.885	.939	.957	.975	.982	.990	1.943	1.123	.801	1.962
24	5.70	9.1	g.+	.906	1.635	v.g.—	.597	.735	.820	.865	.894	.940	.965	.976	.980	.982	1.871	1.121	.808	1.889
25	4.26	9.5	v.g.+	.894	1.771	g.	.588	.728	.805	.860	.890	.939	.961	.978	.983	.985	1.930	1.100	.812	1.948
26	3.64	9.3	e.	.896	1.768	g.	.608	.740	.815	.857	.890	.940	.961	.974	.976	.980	1.927	1.100	.814	1.946
27	3.49	7.3	v.g.+	.904	1.761	e.—	.587	.731	.819	.866	.900	.952	.970	.981	.986	.986	1.919	1.098	.823	1.934
30	8.80	11.6	e.	.914	1.673	p.+	.625	.750	.826	.875	.903	.958	.975	.980	.982	.982	1.877	1.136	.805	1.900
Oct. 1	5.69	11.2	v.g.	.877	1.761	v.g.	.569	.706	.782	.834	.870	.931	.960	.974	.977	.976	1.928	1.107	.792	1.951
2	4.76	12.8	e.	.895	1.669	e.	.547	.702	.794	.852	.890	.941	.961	.975	.980	.982	1.923	1.167	.767	1.949
3	4.79	18.0	e.—	.900	1.684	v.g.—	.600	.740	.820	.870	.900	.949	.972	.986	.986	.986	1.867	1.130	.796	1.903
6	3.46	7.9	v.g.+	.893	1.795	e.—	.583	.729	.816	.870	.911	.950	.967	.980	.981	.986	1.926	1.081	.825	1.942
7	4.07	10.3	e.	.905	1.721	e.—	.605	.740	.816	.862	.897	.951	.970	.975	.980	.982	1.916	1.125	.804	1.937
8	4.52	15.3	v.g.	.875	1.702	e.—	.542	.685	.774	.825	.871	.930	.950	.967	.970	.975	1.884	1.125	.778	1.915
9	3.86	14.6	v.g.	.857	1.810	e.	.512	.685	.785	.824	.873	.930	.947	.964	.971	.976	2.030	1.139	.752	2.062

TABLE 37.—*Solar-constant values, Mount Wilson, 1918.*

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry.			Bolometry.															
			Grade.	Apparent atmospheric transmission a.	Apparent solar constant A_o.	Grade.	Atmospheric transmission for different wave lengths.										Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.
							μ 0.35	μ 0.40	μ 0.45	μ 0.50	μ 0.60	μ 0.70	μ 0.80	μ 1.00	μ 1.20	μ 1.60				
	mm.	*mm.*																		
June 23	8.66	9.8	v.g.+	0.831	1.806	p.	0.573	0.673	0.741	0.779	0.809	0.863	0.878	0.897	0.912	0.927	1.998	1.117	0.743	2.019
24	5.86	3.8	p.	.878	1.797	g.—	.607	.741	.817	.845	.873	.916	.943	.945	.943	.943	1.884	1.052	.834	1.892
25	4.78	5.3	e.	.906	1.752	v.g.—	.609	.734	.803	.851	.894	.945	.963	.973	.971	.975	1.932	1.108	.816	1.943
26	4.37	22.8	v.g.	.841	1.723	e.—	.519	.646	.735	.795	.844	.918	.944	.960	.963	.970	1.871	1.112	.755	1.918
29	5.12	25.0	v.g.	.863	1.604	v.g.	.530	.653	.733	.792	.838	.895	.922	.949	.958	.964	1.891	1.211	.712	1.943
July 3	9.32	26.0	e.—	.863	1.685	v.g.—	.542	.680	.756	.813	.860	.928	.950	.965	.967	.972	1.880	1.147	.752	1.934
4	7.91	21.5	v.g.	.869	1.732	v.g.	.582	.698	.783	.840	.875	.942	.965	.976	.979	.982	1.890	1.117	.777	1.935
5	7.70	17.9	e.	.895	1.696	e.	.586	.717	.807	.863	.895	.945	.964	.977	.978	.980	1.931	1.160	.771	1.969
6	5.88	15.4	v.g.	.893	1.728	e.	.581	.726	.808	.869	.888	.943	.966	.977	.977	.978	1.925	1.132	.788	1.957
8	5.59	23.4	e.	.849	1.719	e.—	.540	.669	.745	.799	.890	.890	.927	.945	.946	.950	1.930	1.152	.737	1.980
9	5.99	18.8	e.	.871	1.752	v.g.	.542	.683	.765	.820	.854	.930	.956	.964	.965	.964	1.981	1.153	.754	2.022
11	4.38	2.8	v.g.	.902	1.797	g.—	.597	.725	.801	.852	.877	.922	.945	.955	.960	.967	2.014	1.123	.802	2.020
14	7.79	13.8	e.	.897	1.692	e.—	.560	.710	.795	.850	.876	.932	.952	.963	.964	.960	1.942	1.164	.770	1.971
15	5.30	11.4	e.—	.897	1.700	g.+	.555	.712	.811	.853	.878	.932	.954	.970	.978	.978	1.919	1.142	.786	1.942
21	2.64	11.0	e.—	.902	1.725	v.g.+	.578	.731	.826	.850	.883	.958	.973	.981	.984	.984	1.916	1.122	.803	1.938
22	4.53	10.9	e.	.886	1.753	v.g.	.570	.704	.795	.850	.880	.937	.960	.972	.976	.979	1.907	1.100	.805	1.929
23	5.22	11.2	v.g.—	.893	1.775	g.	.599	.729	.814	.867	.907	.953	.971	.990	.992	.990	1.897	1.081	.826	1.920
24	2.64	4.5	g.	.916	1.720	g.+	.636	.760	.835	.865	.885	.940	.970	.982	.986	.985	1.907	1.113	.822	1.916
25	5.27	3.5	g.—	.890	1.805	v.g.	.550	.689	.785	.855	.885	.939	.961	.969	.970	.975	1.961	1.090	.816	1.968
26	4.85	4.1	g.+	.893	1.827	v.g.	.580	.715	.812	.860	.886	.940	.962	.979	.979	.979	1.949	1.071	.833	1.958
27	1.63	1.6	v.g.	.904	1.795	e.—	.608	.735	.815	.867	.890	.950	.972	.985	.988	.989	1.946	1.085	.833	1.949
28	1.76	4.6	v.g.+	.906	1.776	e.—	.604	.739	.815	.865	.878	.946	.968	.977	.977	.982	1.938	1.096	.826	1.947
29	4.03	22.3	g.—	.875	1.631	g.	.566	.680	.770	.824	.856	.933	.963	.980	.982	.981	1.862	1.169	.748	1.908
Aug. 2	8.81	23.2	v.g.+	.897	1.628	e.—	.605	.725	.806	.853	.884	.951	.975	.984	.985	.990	1.838	1.156	.775	1.885
3	5.66	27.9	g.	.840	1.701	g.	.484	.630	.718	.775	.826	.903	.941	.962	.963	.972	1.888	1.144	.734	1.946
4	6.19	22.0	v.g.+	.880	1.624	e.	.535	.664	.747	.819	.850	.920	.948	.960	.963	.970	1.909	1.204	.731	1.956
5	9.23	8.0	e.	.904	1.741	v.g.—	.590	.728	.812	.850	.884	.945	.967	.977	.980	.981	1.937	1.121	.806	1.953
8	8.69	7.6	p.	.910	1.692	g.—	.620	.749	.811	.865	.898	.954	.970	.980	.982	.986	1.921	1.143	.795	1.936
9	5.04	12.5	v.g.+	.906	1.676	e.—	.576	.718	.800	(.855)	.884	.936	.956	.977	.981	.979	1.921	1.161	.781	1.946
10	3.88	20.9	g.	.909	1.674	g.	.582	.711	.786	.843	.879	.923	.955	.965	.965	.966	1.918	1.171	.776	1.962
11	3.70	21.1	e.	.873	1.690	v.g.	.578	.706	.778	.834	.870	.923	.950	.966	.971	.978	1.912	1.158	.753	1.956
12	5.06	20.7	v.g.—	.843	1.761	p.	.540	.660	.731	.785	.832	.902	.936	.957	.962	.968	1.964	1.139	.740	2.008
13	6.49	21.1	e.	.859	1.764	e.	.569	.696	.781	.836	.865	.930	.954	.974	.974	.972	1.894	1.098	.782	1.938
14	6.10	14.3	g.—	.892	1.723	p.	.594	.719	.790	.845	.871	.946	.969	.975	.981	.983	1.919	1.130	.789	1.948
19	5.57	6.8	e.	.902	1.740	g.+	.591	.719	.803	.850	.889	.940	.960	.971	.972	.979	1.928	1.116	.808	1.942
20	5.20	4.3	e.	.907	1.740	e.	.589	.717	.798	.854	.888	.935	.963	.980	.984	.987	1.929	1.113	.814	1.938
21	3.82	2.6	e.	.901	1.812	v.g.—	.592	.723	.812	.859	.882	.944	.963	.978	.981	.982	1.965	1.088	.828	1.971
22	3.32	5.1	e.	.905	1.770	e.+	.582	.732	.816	.870	.894	.943	.965	.978	.983	.985	1.938	1.101	.822	1.949
23	5.53	12.0	e.—	.895	1.732	e.	.594	.732	.807	.863	.890	.944	.957	.966	.968	.972	1.932	1.129	.792	1.957
29	8.97	27.1	e.+	.884	1.662	e.+	.549	.700	.803	.854	.891	.946	.967	.979	.981	.982	1.872	1.160	.761	1.929
Sept. 1	2.93	11.9	e.	.902	1.758	v.g.	.585	.731	.816	.860	.890	.946	.965	.978	.979	.975	1.954	1.125	.801	1.979
2	3.97	17.6	p.	.906	1.617	p.	.600	.718	.792	.854	.887	.940	.965	.982	.983	.984	1.885	1.188	.763	1.921
5	5.07	10.2	v.g.+	.895	1.675	g.+	.565	.708	.795	.855	.894	.949	.968	.974	.975	.975	1.930	1.164	.768	1.951
6	5.81	15.6	v.g.—	.890	1.698	v.g.—	.544	.701	.794	.840	.876	.930	.956	.974	.978	.981	1.923	1.159	.770	1.956
9	2.92	5.4	v.g.	.907	1.689	p.	.565	.734	.816	.876	.908	.952	.970	.973	.972	.976	1.860	1.102	.823	1.871
16	6.66	15.3	v.g.	.894	1.737	v.g.	.585	.717	.796	.854	.887	.939	.957	.969	.966	.969	1.964	1.148	.777	1.997
19	6.34	5.4	v.g.—	.906	1.792	p.	.623	.728	.808	.865	.897	.955	.964	.972	.976	.978	1.980	1.110	.815	1.991
20	1.85	4.5	e.—	.908	1.774	e.	.625	.751	.825	.872	.895	.946	.973	.974	.975	.983	1.946	1.102	.823	1.956
24	3.92	7.4	e.	.905	1.742	v.g.	.598	.731	.814	.858	.900	.949	.970	.976	.976	.985	1.929	1.116	.811	1.944
25	4.81	10.1	e.—	.882	1.788	e.	.566	.691	.766	.820	.866	.923	.948	.962	.967	.973	2.003	1.132	.779	2.025
26	2.75	5.6	g.	.897	1.784	v.g.—	.600	.734	.813	.865	.902	.948	.963	.971	.975	.983	1.951	1.100	.815	1.963
Oct. 2	10.07	16.4	p.	.910	1.652	p.	.570	.713	.805	.867	.895	.954	.975	.990	.988	.990	1.868	1.151	.791	1.901
9	8.94	14.2	v.g.—	.879	1.795	v.g.	.565	.714	.802	.857	.887	.939	.958	.974	.975	.972	1.920	1.086	.809	1.950
10	6.09	10.6	e.	.904	1.737	e.	.585	.735	.821	.871	.888	.947	.966	.974	.974	.979	1.920	1.118	.807	1.942
11	4.38	10.2	e.	.904	1.753	g.	.590	.721	.811	.860	.896	.937	.965	.975	.976	.975	1.960	1.130	.799	1.981
12	5.17	12.6	e.—	.887	1.747	e.—	.550	.689	.782	.834	.865	.921	.956	.971	.972	.977	1.968	1.141	.777	1.995

Table 38.—*Solar-constant values, Mount Wilson, 1919.*

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry.			Bolometry.	Atmospheric transmission for different wave lengths.										Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.	$E'_o+2.2\%$.[1]
			Grade.	Apparent atmospheric transmission a.	Apparent solar constant A_o.	Grade.	0.35 μ	0.40 μ	0.45 μ	0.50 μ	0.60 μ	0.70 μ	0.80 μ	1.00 μ	1.20 μ	1.60 μ					
	mm.	mm.																			
June 15	3.97	4.1	e.	0.887	1.736	p.	0.627	0.722	0.795	0.818	0.860	0.940	0.958	0.967	0.972	0.985	1.840	1.064	0.834	1.848	1.889
16	4.64	3.0	e.	.884	1.802	g.	.664	.730	.779	.824	.880	.945	.960	.969	.972	.980	1.905	1.060	.834	1.911	1.953
17	3.07	3.0	e.	.895	1.811	p.	.605	.719	.755	.845	.865	.924	.958	.982	.995	.999	1.967	1.089	.822	1.973	2.016
18	3.59	3.7	e.	.888	1.807	v. g.	.614	.733	.807	.848	.870	.928	.955	.974	.980	.990	1.937	1.076	.825	1.944	1.986
21	3.43	5.3	e.	.884	1.816	e.—	.649	.734	.795	.831	.880	.934	.960	.975	.978	.978	1.944	1.077	.821	1.956	1.999
22	2.48	5.4	e.	.903	1.759	g.+	.660	.768	.828	.867	.895	.945	.965	.980	.980	.984	1.908	1.090	.828	1.917	1.959
23	2.81	4.8	v. g.	.907	1.737	g.+	.683	.760	.815	.855	.903	.948	.968	.979	.980	.986	1.881	1.089	.833	1.892	1.934
24	3.31	7.6	e.	.893	1.767	v. g.	.655	.742	.814	.870	.882	.940	.965	.980	.983	.985	1.887	1.076	.830	1.902	1.944
25	2.08	5.9	e.	.901	1.721	e.	.673	.745	.805	.857	.881	.937	.968	.984	.990	.990	1.889	1.105	.815	1.902	1.944
26	2.76	11.2	e.—	.879	1.724	g.	.612	.710	.776	.825	.873	.925	.950	.970	.975	.978	1.865	1.095	.803	1.888	1.929
27	2.62	4.6	e.—	.893	1.744	v. g.	.657	.744	.804	.848	.872	.920	.950	.962	.968	.974	1.889	1.086	.822	1.895	1.937
28	3.92	7.7	v. g.—	.891	1.766	v. g. (?)	.631	.744	.830	.885	.910	.946	.970	.979	.985	.985	1.887	1.091	.817	1.926	1.969
29	1.40	9.2	v. g.	.894	1.757	g.	.587	.757	.822	.860	.904	.945	.955	.960	.965	.975	1.914	1.100	.813	1.932	1.974
30	3.23	6.4	v. g.—	.893	1.782	g.—	.592	.750	.825	.863	.895	.948	.971	.985	.985	.983	1.908	1.078	.831	1.921	1.963
July 1	2.26	7.9	e.	.897	1.763	e.—	.688	.772	.835	.874	.904	.960	.968	.980	.975	.975	1.903	1.088	.824	1.919	1.961
2	2.82	11.8	e.—	.904	1.700	g.+	.635	.760	.842	.890	.900	.952	.965	.975	.980	.984	1.848	1.101	.821	1.871	1.912
3	1.34	10.1	v. g.	.886	1.736	g.	.602	.730	.805	.850	.880	.926	.954	.975	.982	.995	1.906	1.109	.799	1.926	1.969
6	3.75	12.2	e.	.885	1.751	g.+	.628	.742	.810	.857	.892	.934	.955	.970	.970	.980	1.885	1.090	.812	1.909	1.951
7	3.92	13.4	v. g.	.889	1.716	e.—	.661	.745	.811	.865	.898	.929	.955	.979	.981	.985	1.875	1.108	.802	1.902	1.944
9	9.77	27.3	v. g.—	.843	1.742	g.	.578	.676	.749	.800	.848	.893	.924	.952	.964	.975	1.893	1.119	.753	1.950	1.993
10	7.32	20.7	e.	.895	1.655	v. g.	......	.743	.810	.860	.900	.945	.963	.980	.989	.993	1.863	1.150	.778	1.904	1.946
11	7.68	25.3	e.—	.871	1.625	g.	.588	.706	.775	.820	.858	.915	.940	.975	.970	.985	1.852	1.171	.744	1.903	1.945
14	10.40	25.3	e.	.863	1.721	g.	......	.704	.772	.820	.872	.915	.942	.970	.980	.990	1.870	1.117	.773	1.922	1.964
20	10.13	24.8	p.	(.869)	1.545	v. p.	.605	.710	.764	.813	.855	.914	.933	.950	.948	.975	1.799	1.068	.814	1.804	1.844
21	10.57	26.2	v. g.	.843	1.766	g.—	.592	.700	.772	.816	.877	.905	.936	.955	.965	.982	1.898	1.106	.762	1.953	1.996
22	7.11	6.7	v. g.—	.878	1.738	e.—	.621	.736	.813	.865	.905	.923	.948	.975	.985	.987	1.867	1.094	.803	1.901	1.943
23	6.95	4.2	e.	.857	1.653	v. g.+	.583	.696	.747	.790	.846	.895	.936	.955	.962	.965	1.852	1.155	.742	1.910	1.952
24	7.38	3.6	g.	.858	1.657	g.	.603	.698	.762	.807	.865	.899	.924	.949	.954	.965	1.853	1.148	.747	1.903	1.945
27	3.34	18.4	v. g.	.836	1.732	p.	.575	.650	.715	.768	.810	.885	.915	.952	.965	.979	1.902	1.121	.746	1.941	1.983
29	2.16	3.6	e.	.893	1.840	v. g.	.640	.745	.820	.865	.905	.952	.975	.980	.975	.980	1.933	1.055	.846	1.942	1.985
30	2.70	3.0	v. g.	.906	1.779	v. g.+	.663	.755	.822	.872	.896	.950	.972	.988	.993	1.000	1.901	1.072	.845	1.907	1.949
31	1.54	3.6	v. g.	.908	1.763	v. g.—	.624	.752	.817	.868	.915	.968	.970	.980	.987	.995	1.876	1.069	.849	1.884	1.925
Aug. 1	5.17	12.2	v. g.	.895	1.678	v. g.—	.608	.718	.795	.850	.877	.940	.968	.980	.975	.975	1.894	1.144	.782	1.919	1.961
2	2.73	3.8	e.—	.908	1.728	v. g.—	.629	.733	.805	.855	.895	.937	.966	.982	.985	.990	1.884	1.095	.829	1.892	1.934
3	1.92	3.9	v. g.	.902	1.801	v. g.—	.650	.750	.817	.855	.890	.935	.958	.982	.990	.995	1.912	1.064	.848	1.916	1.958
4	2.13	3.6	e.	.905	1.772	g.+	.680	.755	.827	.865	.890	.947	.958	.970	.965	.983	1.904	1.077	.840	1.908	1.950
5	2.74	5.9	v. g.	.891	1.784	g.	.635	.758	.802	.865	.881	.940	.960	.976	.980	.982	1.908	1.076	.828	1.920	1.962
7	6.00	14.4	v. g.	.881	1.617	p.	.625	.712	.790	.842	.872	.928	.962	.990	.992	.990	1.816	1.147	.768	1.855	1.896
10	3.59	10.3	e.—	.897	1.744	e.	.617	.735	.826	.875	.907	.951	.966	.975	.965	.975	1.896	1.099	.816	1.916	1.958
12	1.44	9.0	v. g.	.897	1.757	p.+	.593	.695	.753	.798	.860	.915	.950	.970	.976	.994	1.862	1.070	.838	1.880	1.921
13	1.22	8.6	e.—	.894	1.769	e.	.658	.753	.823	.878	.904	.950	.970	.980	.980	.985	1.858	1.060	.843	1.876	1.917
14	1.82	6.7	e.—	.905	1.724	v. g.+	.626	.750	.825	.873	.895	.955	.970	.974	.975	.984	1.890	1.104	.820	1.904	1.946
19	7.18	22.3	v. g.	.866	1.672	v. g.—	.616	.719	.798	.850	.878	.934	.945	.966	.974	.978	1.836	1.126	.769	1.883	1.924
22	6.27	12.8	e.	.853	1.664	g.	......	.650	.733	.790	.858	.905	.927	.953	.960	.975	1.858	1.133	.753	1.885	1.927
23	4.36	11.8	g.	.847	1.745	p. (?)	568	.650	.718	.770	.842	.881	.912	.950	.962	.976	1.920	1.114	.760	1.944	1.986
28	5.64	19.7	e.	.799	1.659	p.	.567	.668	.732	.771	.805	.835	.873	.918	.935	.962	1.880	1.158	.690	1.922	1.964
29	8.69	21.0	v. g.+	.836	1.682	v. g.—	.600	.670	.725	.770	.814	.875	.913	.948	.950	.962	1.880	1.141	.733	1.919	1.961
30	7.24	18.0	e.	.847	1.641	g.	.588	.673	.731	.770	.834	.883	.908	.937	.950	.965	1.873	1.164	.728	1.910	1.952
Sept. 1	6.11	15.9	e.	.882	1.726	g.	.638	.744	.812	.854	.885	.926	.952	.975	.978	.985	1.876	1.106	.797	1.909	1.951
2	4.03	8.0	v. g.	.900	1.749	v. g.	.656	.775	.835	.880	.900	.950	.973	.983	.965	.988	1.864	1.075	.837	1.880	1.921
3	3.42	14.3	v. g.	.894	1.730	v. g.	.642	.739	.805	.854	.895	.942	.965	.981	.985	.982	1.880	1.103	.810	1.909	1.951
4	4.54	4.1	v. g.+	.910	1.771	v. g.	.662	.764	.831	.868	.907	.950	.970	.983	.987	.988	1.887	1.070	.850	1.895	1.937

[1] As explained in the text, defective stellite mirrors used in 1919 introduced bad definition of the spectrum, from which low values of the solar constant resulted. The correction, plus 2.2 per cent, was determined from Calama data.

TABLE 38.—*Solar-constant values, Mount Wilson, 1919*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry.			Bolometry.												Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.	E'_o+2.2%.
			Grade.	Apparent atmospheric transmission a.	Apparent solar constant A_o.	Grade.	Atmospheric transmission for different wave lengths.															
							μ 0.35	μ 0.40	μ 0.45	μ 0.50	μ 0.60	μ 0.70	μ 0.80	μ 1.00	1.20	μ 1.60					
	mm.	*mm.*																			
Sept. 5	1.36	3.4	v.g.	0.906	1.795	e.	0.650	0.762	0.832	0.875	0.902	0.945	0.972	0.985	0.989	0.992	1.884	1.053	0.860	1.891	1.933
6	2.95	5.0	v.g.	.901	1.758	e.	.665	.750	.805	.845	.898	.940	.973	.981	.980	.975	1.884	1.077	.837	1.894	1.936
7	4.40	8.0	e.	.907	1.724	g.	.630	.742	.810	.865	.900	.934	.963	.980	.989	.995	1.876	1.097	.827	1.892	1.934
8	3.75	11.4	g.	.902	1.706	g.	.668	.758	.820	.863	.895	.940	.967	.982	.987	.992	1.877	1.114	.810	1.900	1.942
11	2.54	6.1	v.g.	.891	1.828	v.g.	.660	.754	.818	.857	.896	.935	.953	.972	.975	.982	1.920	1.077	.827	1.932	1.975
12	1.71	13.5	e.—	.908	1.773	e.	.682	.781	.828	.870	.893	.950	.976	.989	.995	.995	1.891	1.071	.848	1.899	1.941
13	5.68	13.5	g.	.895	1.729	v.g.+	.650	.755	.820	.868	.900	.950	.970	.983	.979	.980	1.887	1.108	.808	1.915	1.957
16	2.20	3.6	e.	.890	1.726	e.—	.632	.728	.797	.845	.884	.930	.960	.984	.989	.994	1.897	1.115	.798	1.925	1.967
17	4.28	4.4	g.	.910	1.748	e.	.660	.760	.825	.870	.900	.948	.971	.985	.980	.994	1.886	1.084	.839	1.894	1.936
18	4.44	8.4	v.g.	.880	1.726	p.	.638	.742	.802	.841	.887	.927	.952	.968	.972	.975	1.830	1.069	.823	1.845	1.885
19	4.95	12.5	g.	.871	1.683	g.—	.617	.708	.770	.813	.860	.910	.935	.950	.958	.970	1.897	1.143	.762	1.923	1.965
20	4.55	14.1	v.g.	.866	1.731	e.	.604	.703	.770	.822	.860	.911	.933	.960	.964	.969	1.888	1.107	.782	1.917	1.959
21	3.92	11.2	v.g.	.881	1.716	(g.)	.625	.720	.788	.840	.882	.931	.954	.970	.978	.985	1.896	1.118	.788	1.918	1.960

TABLE 39.—*Solar-constant values, Mount Wilson, 1920.*

Date.	Pressure water vapor.	Precipitable water.	Pyrheliometry. Grade.	Pyrheliometry. Apparent atmospheric transmission a.	Pyrheliometry. Apparent solar constant A_o.	Bolometry. Grade.	Atmospheric transmission for different wave lengths. 0.35μ	0.40μ	0.45μ	0.50μ	0.60μ	0.70μ	0.80μ	1.00μ	1.20μ	1.60μ	Solar constant E_o.	Ratio $\frac{E'_o}{A_o}$.	Atmospheric transmission $\frac{A_o a}{E'_o}$	Solar constant corrected for zero water vapor E'_o.
	mm.	*mm.*																		
July 8	2.00	14.0	v.g.	0.899	1.723	e.	0.622	0.747	0.828	0.886	0.904	0.954	0.975	0.988	0.981	0.986	1.898	1.118	0.804	1.926
9	2.59	8.6	v.g.	.900	1.785	v.g.	.653	.758	.834	.873	.902	.952	.972	.982	.983	.984	1.924	1.088	.827	1.942
10	3.20	11.8	e.—	.896	1.742	e.—	.612	.744	.817	.869	.902	.951	.969	.982	.977	.995	1.913	1.112	.806	1.937
11	3.60	5.7	v.g.—	.895	1.823	v.g.—	.676	.746	.837	.895	.904	.959	.973	.980	.980	.991	1.920	1.060	.844	1.932
12	5.33	4.8	v.g.—	.914	1.758	v.g.—	.625	.760	.833	.869	.893	.956	.985	.993	.983	.993	1.939	1.109	.824	1.949
13	4.65	8.5	e.—	.902	1.750	e.—	.664	.741	.825	.891	.887	.962	.977	.972	.970	1.000	1.910	1.101	.819	1.927
14	2.88	11.2	g.+	.885	1.726	g.+	.631	.748	.830	.865	.883	.963	.982	.983	.987	.995	1.877	1.100	.805	1.899
17	5.62	15.2	e.	.896	1.721	e.	.643	.737	.807	.878	.902	.950	.970	.982	.977	.977	1.902	1.123	.799	1.934
18	6.40	12.9	v.g.	.900	1.736	v.g.—	.670	.769	.826	.906	.912	.944	.967	.989	.997	.993	1.892	1.105	.815	1.919
19	2.76	4.4	g.+	.904	1.805	v.g.	.622	.755	.834	.887	.908	.959	.978	.988	.979	.993	1.918	1.068	.820	1.927
20	1.99	8.3	v.g.+	.907	1.750	v.g.+	.650	.746	.837	.885	.904	.930	.974	.985	.984	.991	1.914	1.103	.822	1.931
21[1]	2.42	16.2	p.	.905	1.680	v.g.	.621	.725	.815	.862	.906	.949	.973	.982	.976	.986	1.824	1.105	.819	1.856
24	6.87	20.0	v.g.	.879	1.708	v.g.—	.625	.694	.808	.842	.897	.945	.972	.991	.990	.977	1.891	1.131	.777	1.932
25	3.27	14.1	g.	.891	1.732	v.g.+	.649	.729	.814	.869	.891	.948	.972	.989	.984	.986	1.891	1.107	.805	1.918
26	2.85	16.2	v.g.+	.896	1.714	v.g.—	.612	.723	.815	.857	.887	.942	.973	.978	.987	.991	1.925	1.130	.793	1.958
28	5.97	19.1	p.+	.905	1.684	e.—	.619	.710	.801	.866	.893	.931	.957	.962	.976	.970	1.873	1.135	.797	1.912
29	6.82	22.1	v.g.+	.884	1.623	e.—	.578	.732	.789	.841	.867	.928	.947	.979	.962	.984	1.875	1.185	.746	1.924
Aug. 3[2]	10.60	25.2	p.	.840	1.730	g.	.501	.574	.711	.768	.809	.885	.933	.964	.953	.982	2.033	1.208	.695	2.090
4	9.13	17.5	v.g.	.886	1.731	v.g.—	.598	.707	.824	.843	.893	.949	.980	.991	.988	.973	1.890	1.113	.805	1.926
5	4.41	10.9	v.g.	.877	1.751	v.g.	.638	.745	.840	.873	.904	.956	.975	.991	.990	.986	1.899	1.097	.799	1.921
7	4.36	21.4	v.g.	.879	1.702	e.+	.608	.734	.810	.861	.881	.926	.961	.975	.977	.982	1.901	1.143	.769	1.945
8	6.00	28.5	v.g.—	.858	1.622	g.	.614	.690	.777	.822	.869	.912	.948	.957	.957	.968	1.853	1.179	.728	1.912
9	5.75	17.9	v.g.	.886	1.693	v.g.	.643	.727	.795	.853	.897	.946	.974	.977	.980	.982	1.888	1.136	.780	1.924
12	7.35	21.2	v.g.	.875	1.662	v.g.+	.589	.724	.791	.824	.855	.921	.956	.971	.973	.984	1.906	1.174	.745	1.951
13	7.74	18.1	v.g.	.837	1.715	v.g.	.544	.627	.720	.770	.818	.889	.924	.940	.937	.973	1.930	1.148	.729	1.968
14	9.37	15.8	v.g.	.823	1.667	v.g.	.531	.614	.682	.756	.791	.862	.914	.939	.940	.964	1.890	1.153	.714	1.922
15	7.74	15.1	v.g.—	.834	1.588	v.g.—	.594	.578	.680	.776	.807	.873	.913	.955	.946	.955	1.872	1.198	.696	1.903
16	8.37	18.1	v.g.—	.844	1.712	e.	.564	.661	.738	.804	.828	.897	.929	.954	.959	.964	1.932	1.151	.733	1.970
17	7.83	15.5	v.g.	.838	1.746	e.	.537	.662	.730	.776	.822	.879	.913	.918	.939	.959	1.982	1.155	.726	2.016
18	7.38	8.2	v.g.	.902	1.750	e.	.653	.736	.801	.863	.910	.950	.966	.988	.982	.991	1.920	1.107	.815	1.937
19	3.39	5.0	v.g.	.912	1.791	v.g.—	.622	.788	.839	.876	.902	.959	.976	.989	.982	.991	1.913	1.073	.850	1.922
20	5.18	8.5	v.g.+	.898	1.776	e.	.635	.714	.815	.865	.902	.943	.961	.974	.983	.980	1.958	1.113	.795	1.976
21	5.26	9.3	e.—	.891	1.788	e.	.638	.744	.804	.871	.887	.953	.974	.979	.972	.973	1.916	1.082	.824	1.935
22	3.00	5.6	v.g.	.902	1.803	g.	.628	.727	.801	.865	.893	.942	.979	.987	.985	.993	1.978	1.097	.822	1.990
23[3]	4.42	14.6	p.	......	....	g.—	.686	.719	.791	.848	.889	.943	.959	.980	.978	.984	1.837	....	......	1.866
27	5.32	5.7	v.g.—	.910	1.745	g.+	.646	.773	.816	.882	.897	.950	.970	.984	.981	1.000	1.901	1.096	.810	1.912
29	5.38	14.4	e.—	.897	1.706	e.	.643	.775	.811	.859	.904	.954	.973	.983	.980	.986	1.887	1.123	.799	1.915
30	7.16	14.8	e.	.877	1.746	e.—	.596	.703	.780	.843	.859	.921	.946	.954	.964	.980	1.963	1.142	.768	1.994
Sept. 2	5.28	15.4	v.g.+	.869	1.671	g.+	.588	.705	.782	.812	.859	.922	.952	.971	.974	.982	1.880	1.144	.760	1.912
3	4.81	19.8	e.—	.840	1.653	e.	.521	.608	.705	.753	.832	.894	.931	.955	.959	.984	1.877	1.160	.724	1.917
4	5.18	16.7	v.g.	.894	1.660	v.g.	.605	.744	.792	.845	.871	.932	.968	.988	.980	.989	1.890	1.158	.772	1.923
5	4.62	13.3	v.g.	.896	1.708	v.g.	.702	.770	.802	.864	.900	.951	.972	.981	.975	.977	1.893	1.124	.797	1.920
6	4.56	7.1	v.g.—	.915	1.705	v.g.—	.661	.733	.810	.875	.912	.951	.977	.993	.994	.991	1.877	1.109	.825	1.891

[1] Sky very hazy, streaky, and variable. Clouds form in southeast at end.
[2] Sky very hazy. Cirri low in east.
[3] Cirri in south and west reaching sun after fourth observation.

SOLAR CONSTANT AND ATMOSPHERIC TRANSMISSION AT HUMP MOUNTAIN, NORTH CAROLINA, AND CALAMA, CHILE, 1917 TO 1920.

In the following tables we give results similar to those given in the preceding tables for Mount Wilson, including the results of solar-constant investigations at Hump Mountain, North Carolina, and Calama, Chile. Owing to differences in the method of obtaining and stating the results by the observers, the tables are somewhat abbreviated as compared with those heretofore given for Mount Wilson. Column 1 gives the date; column 2, the pressure of aqueous vapor occurring during the observations expressed in millimeters of mercury; column 3, the precipitable water as determined by Fowle's method, indicating the number of millimeters of liquid water which would result by precipitating all of the vapor of water in a column vertically above the observer and extending to the limit of the atmosphere; column 4 gives the apparent solar constant A_o, obtained from pyrheliometry alone, as described on a preceding page. Columns 5 to 15 relate to spectrobolometry alone. Column 5 gives the grade of the spectrobolometric work, obtained as described in previous volumes of the Annals and above. Columns 6 to 15 give the coefficient of atmospheric transmission for different wave lengths. The wave lengths selected are nearly but not quite identical with those which are selected for giving the similar results of the Mount Wilson observations. Column 16 gives the ratio of the solar constant to the apparent solar constant, determined by pyrheliometry alone, and column 17 gives the solar constant itself, as the result of the combined pyrheliometry and spectrobolometry.

No secondary correction is applied to the results of these observations for the effect of water vapor. An investigation was made of the results of a great number of days at Calama, Chile, and no dependence of the solar constant on the quantity of water vapor prevailing could be observed. The results at Hump Mountain are so unreliable, on account of the changes in the state of the atmosphere, that it would be useless to attempt to improve them by making a residual water-vapor correction.

From and after July, 1919, a new method of observing has been introduced at Calama, Chile. This leads to some alteration in the method of reduction but none in the form of the table, except as regards the grade. This has been altered by the introduction of the letters "S," meaning satisfactory, and "U," unsatisfactory, in place of the other symbols hitherto employed. Furthermore, since several values are now obtained on each day of observation, the weighted mean value alone is given in the table. All of the individual values are given in current issues of the Monthly Weather Review, published by the United States Weather Bureau. As stated in Chapter V below, we found it necessary to correct the preliminary results obtained by the short method at Calama for certain imperfections in the so-called "function-transmission" plots used in deriving them. These corrections were published in the Monthly Weather Review for September, 1921. The corrected weighted mean values appear in the final column of the Calama table. The corrections were only necessary from July 1, 1919, to July 26, 1920.

TABLE 40.—*Solar-constant values, Hump Mountain, 1917.*

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o.	Bolometry.											Ratio $\frac{E_o}{A_o}$	Solar constant E_o.
				Atmospheric transmission for different wave lengths.												
				Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610		
	mm.	*mm.*														
June 17	4.40	1.6	....	v.g.	0.564	0.716	0.804	0.845	0.900	0.937	0.963	0.970	0.981	0.984	....	1.836
18	7.48	8.7	....	g.	.619	.672	.754	.769	.847	.890	.929	.957	.965	.960	....	1.865
30	7.13	5.3	....	v.g.	.562	.678	.764	.825	.877	.908	.948	.950	.952	.979	....	1.908
July 1	9.54	11.4	....	v.g.	.593	.656	.761	.812	.858	.903	.939	.954	.961	.962	....	1.896
2	10.61	14.8	....	g.+	.505	.617	.708	.775	.832	.875	.930	.945	.939	.976	....	1.950
Aug. 4	10.48	11.6	....	g.—	.564	.654	.746	.799	.856	.895	.939	.944	.940	.969	....	1.951
6	8.24	10.4	....	g.—	.466	.575	.669	.717	.814	.864	.924	.942	.945	.973	....	1.976
11	8.30	12.2	....	g.	.472	.532	.648	.708	.801	.855	.890	.931	.943	.966	....	1.966
18	8.54	4.3	....	v.g.	.625	.690	.791	.845	.890	.932	.956	.971	.978	.985	....	1.869
25	8.21	7.1	1.876	g.+	.544	.641	.734	.794	.865	.894	.920	.932	.936	.976	1.118	2.098
26	5.78	5.1	1.694	e.—	.605	.718	.815	.858	.897	.943	.965	.976	.970	.974	1.118	1.895
28	10.16	13.9	1.620	g.	.500	.583	.704	.735	.815	.857	.910	.929	.943	.964	1.156	1.873
Sept. 12	4.60	5.0	1.678	v.g.	.607	.700	.806	.849	.888	.916	.948	.969	.974	.978	1.120	1.880
13	2.30	2.3	1.783	v.g.+	.585	.698	.792	.849	.887	.928	.957	.965	.970	.977	1.043	1.860
18	6.57	6.6	1.631	e.	.541	.676	.788	.830	.882	.921	.955	.968	.965	.980	1.110	1.812
26	8.40	14.7	1.651	v.g.	.558	.670	.769	.825	.882	.916	.953	.959	.959	.936	1.151	1.901
Oct. 2	5.34	4.7	1.728	v.g.	.562	.710	.804	.856	.908	.942	.964	.973	.966	.980	1.097	1.897
3	6.67	5.3	1.744	v.g.	.554	.670	.778	.813	.873	.922	.951	.970	.963	.987	1.125	1.962
5	7.58	14.0	1.652	v.g.	.591	.738	.802	.853	.900	.935	.959	.963	.961	.983	1.140	1.885
10	4.33	5.1	1.659	v.g.—	.556	.681	.788	.839	.890	.927	.963	.974	.973	.967	1.128	1.871
13	3.15	3.4	1.720	v.g.	.595	.715	.800	.855	.900	.930	.960	.973	.976	.985	1.117	1.923
14	2.15	7.2	1.661	g.—	.503	.646	.771	.801	.875	.911	.953	.960	.961	.985	1.138	1.891
15	4.36	11.1	1.709	g.	.513	.620	.740	.790	.840	.895	.927	.961	.961	.965	1.149	1.964
16	8.40	12.8	1.581	v.g.—	.563	.696	.781	.839	.888	.935	.955	.965	.964	.975	1.148	1.817
20	3.85	2.9	1.810	v.g.+	.552	.661	.774	.833	.885	.912	.947	.959	.956	.981	1.096	1.983
21	3.10	5.4	1.622	v.g.	.590	.727	.821	.866	.911	.940	.970	.980	.972	.984	1.126	1.827
22	3.66	8.3	1.741	v.g.+	.540	.683	.787	.828	.871	.921	.939	.960	959	.981	1.129	1.967
28	4.14	5.3	1.743	g.	.559	.740	.823	.855	.910	.939	.969	.971	.967	.980	1.108	1.931
Nov. 4	4.37	6.5	1.688	v.g.+	.565	.700	.808	.868	.910	.941	.968	.978	.974	.990	1.119	1.890
5	4.19	2.9	1.695	g.	.607	.710	.806	.860	.902	.937	.964	.972	.968	.976	1.102	1.869
6	5.03	6.9	1.611	v.g.—	.600	.693	.798	.863	.910	.953	.959	.980	.971	.982	1.114	1.795
7	5.25	4.3	1.747	v.g.	.550	.620	.725	.781	.841	.885	.925	.951	.961	.972	1.140	1.994
8	4.71	3.9	1.712	v.g.—	.539	.700	.801	.840	.890	.925	.957	.972	.972	.978	1.112	1.903
9	4.20	5.8	1.765	g.—	.474	.547	.656	.758	.787	.842	.898	.932	.948	.953	1.160	2.064
10	5.35	5.6	1.532	g.—	.553	.662	.745	.765	.845	.890	.918	.945	.953	.964	1.168	1.790
11	4.75	4.7	1.624	g.	.568	.650	.736	.802	.873	.910	.948	.959	.947	.968	1.162	1.889
15	3.41	3.8	1.805	g.—	.505	.660	.762	.836	.871	.896	.942	.957	.961	.976	1.116	2.029
17	3.47	4.3	1.734	e.—	.585	.718	.810	.855	.901	.932	.961	.965	.971	.978	1.118	1.939
18	4.55	4.9	1.675	e.	.588	.722	.813	.855	.905	.942	.966	.974	.974	.990	1.130	1.895
26	2.67	3.4	1.806	e.—	.555	.670	.770	.827	.870	.915	.942	.961	.961	.978	1.109	2.003
Dec. 17	3.44	3.5	1.615	g.+	.603	.686	.780	.842	.890	.911	.957	.974	.957	.979	1.145	1.850
19	3.15	5.1	1.749	v.g.	.562	.690	.798	.843	.883	.911	.955	.969	.972	.978	1.129	1.976
20	4.42	8.5	1.691	v.g.	.581	.714	.817	.850	.901	.930	.967	.970	.970	.986	1.127	1.906

TABLE 41.—*Solar-constant values, Hump Mountain, 1918.*

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o.	Bolometry.											Ratio $\frac{E_o}{A_o}$.	Solar constant E_o.
				Atmospheric transmission for different wave lengths.												
				Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610		
	mm.	*mm.*														
Jan. 10	2.49	2.6	1.726	v.g.+	0.577	0.720	0.792	0.830	0.875	0.920	0.946	0.961	0.961	0.973	1.125	1.942
12	0.79	1.2	1.761	v.g.—	.614	.670	.791	.858	.929	.939	.964	.967	.968	.975	1.111	1.958
Feb. 4	1.09	1.1	1.777	v.g.	.572	.670	.789	.841	.890	.913	.942	.955	.953	.946	1.112	1.977
6	2.56	5.4	1.670	g.+	.544	.691	.813	.871	.900	.917	.959	.964	.954	.974	1.132	1.891
10	1.99	4.8	1.715	v.g.	.550	.667	.755	.806	.850	.901	.931	.940	.945	.952	1.138	1.953
11	1.81	5.4	1.706	v.g.+	.565	.690	.756	.805	.860	.900	.949	.968	.962	.975	1.125	1.920
17	1.43	1.8	1.726	g.—	.553	.688	.779	.865	.900	.937	.966	.976	.972	.971	1.121	1.935
18	2.81	1.7	1.768	v.g.	.562	.690	.792	.832	.868	.906	.939	.955	.946	.964	1.107	1.957
23	1.82	2.1	1.725	v.g.	.621	.726	.817	.868	.904	.926	.957	.967	.971	.973	1.106	1.908
26	2.19	4.0	1.744	v.g.+	.598	.693	.799	.854	.894	.944	.966	.975	.973	.975	1.103	1.923
28	4.67	7.5	1.605	v.g.—	.568	.694	.807	.835	.879	.915	.949	.967	.972	.982	1.135	1.823
Mar. 2	4.36	3.4	1.724	v.g.	.551	.653	.803	.834	.881	.926	.953	.973	.964	.977	1.109	1.912
8	1.78	1.2	1.744	v.g.+	.574	.687	.791	.835	.878	.912	.961	.975	.968	.987	1.123	1.958
11	1.59	3.0	1.702	v.g.—	.553	.684	.776	.830	.884	.914	.959	.976	.964	.972	1.123	1.914
18	1.19	1.4	1.751	v.g.+	.605	.688	.806	.855	.904	.936	.959	.964	.966	.971	1.103	1.933

TABLE 42.—*Solar-constant values, Calama, Chile, 1918.*

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o.	Bolometry.											Ratio $\frac{E_o}{A_o}$.	Solar constant E_o.
				Atmospheric transmission for different wave lengths.												
				Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610		
	mm.	*mm.*														
July 27	1.55	3.0	1.781	v.g.	0.614	0.731	0.806	0.862	0.903	0.938	0.953	0.960	0.964	0.973	1.091	1.944
28	1.49	4.8	1.756	v.g.+	.605	.704	.816	.852	.894	.935	.956	.964	.954	.970	1.082	1.901
29	1.53	4.6	1.721	v.g.	.601	.717	.806	.857	.900	.930	.963	.970	.967	.970	1.102	1.899
30	1.55	3.9	1.738	v.g.—	.600	.706	.803	.835	.892	.934	.960	.968	.976	.986	1.109	1.929
31	1.57	4.7	1.760	v.g.+	.616	.729	.820	.859	.903	.936	.965	.977	.973	.976	1.097	1.932
Aug. 1	1.34	2.5	1.778	v.g.+	.618	.736	.821	.875	.911	.940	.972	.973	.977	.978	1.093	1.945
3	0.93	1.7	1.811	e.	.629	.736	.817	.868	.906	.932	.954	.969	.976	.970	1.086	1.966
4	0.91	1.6	1.755	v.g.	.625	.736	.804	.845	.905	.933	.951	.971	.968	.969	1.110	1.948
5	0.71	1.3	1.780	e.—	.627	.740	.812	.865	.906	.936	.961	.967	.974	.982	1.097	1.954
6	0.74	1.9	1.798	e.—	.622	.733	.820	.862	.904	.936	.952	.962	.973	.970	1.100	1.972
7	1.16	1.8	1.791	e.	.627	.731	.817	.870	.906	.937	.956	.968	.970	.973	1.087	1.948
8	1.14	1.7	1.821	v.g.+	.633	.739	.815	.867	.904	.935	.958	.966	.970	.973	1.073	1.955
10	1.46	2.6	1.811	e.—	.624	.735	.818	.866	.901	.942	.958	.967	.966	.969	1.078	1.954
11	1.02	2.0	1.845	v.g.—	.626	.736	.815	.868	.907	.935	.957	.961	964	.972	1.065	1.965
12	1.03	2.2	1.801	e.	.623	.736	.831	.866	.900	.940	.957	.969	.969	.975	1.086	1.959
14	2.23	3.9	1.742	v.g.+	.605	.722	.812	.858	.894	.929	.954	.964	.963	.971	1.104	1.925
15	1.58	3.6	1.804	v.g.	.624	.722	.811	.855	.896	.937	.952	.966	.961	.967	1.079	1.947
16	0.88	1.2	1.853	v.g.+	.612	.730	.810	.853	.888	.924	.950	.960	.961	.960	1.072	1.987
17	0.86	4.2	1.699	v.g.+	.632	.743	.824	.874	.912	.947	.955	.962	.964	.966	1.111	1.888
19	2.63	6.8	1.750	e.—	.618	.740	.826	.871	.906	.941	.959	.971	.971	.975	1.113	1.948
20	2.32	3.7	1.764	e.—	.634	.730	.823	.862	.902	.938	.957	.968	.970	.969	1.099	1.940
21	0.80	......	1.874	v.g.+	.612	.728	.823	.866	.900	.936	.957	.966	.970	.973	1.064	1.995
22	0.98	1.2	1.804	e.	.627	.733	.820	.858	.898	.930	.954	.965	.969	.969	1.081	1.953
23	0.99	1.2	1.842	e.+	.615	.732	.811	.859	.896	.920	.954	.965	.966	.970	1.073	1.979
24	1.19	1.6	1.786	g.	.624	.724	.813	.850	.892	.928	.950	.960	.963	.972	1.081	1.932
25	0.88	1.6	1.813	e.—	.620	.726	.813	.856	.894	.925	.953	.962	.965	.968	1.082	1.968
26	1.13	2.3	1.796	v.g.+	.627	.739	.818	.865	.901	.936	.957	.966	.970	.973	1.084	1.949
27	1.12	1.8	1.814	e.	.637	.738	.825	.865	.900	.935	.957	.966	.965	.972	1.078	1.955
28	1.28	3.0	1.738	e.—	.628	.731	.816	.862	.902	.928	.954	.964	.969	.974	1.089	1.894
29	1.52	4.8	1.758	v.g.+	.604	.713	.788	.832	.874	.913	.933	.948	.951	.958	1.111	1.954
30	2.08	6.3	1.755	v.g.+	.583	.682	.778	.829	.872	.910	.936	.951	.956	.961	1.112	1.953
31	3.58	8.0	1.785	g.+	.572	.670	.777	.817	.871	.906	.937	.942	.953	.955	1.124	2.018

TABLE 42.—*Solar-constant values, Calama, Chile, 1918*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o	Bolometry.											Ratio $\frac{E_o}{A_o}$.	Solar constant E_o
					Atmospheric transmission for different wave lengths.											
				Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610		
	mm.	*mm.*														
Sept. 1	2.46	7.0	1.765	v. g.—	0.609	0.715	0.809	0.855	0.891	0.926	0.949	0.962	0.961	0.963	1.121	1.980
6	3.99	10.0	1.700	v. g.+	.588	.700	.794	.845	.891	.928	.954	.964	.964	.971	1.139	1.937
7	1.83	4.3	1.760	e.—	.630	.730	.821	.860	.903	.930	.955	.964	.966	.973	1.108	1.951
8	0.96	1.5	1.754	e.	.658	.740	.828	.868	.905	.940	.965	.970	.970	.976	1.089	1.911
9	0.74	1.5	1.786	v. g.—	.636	.748	.831	.866	.904	.936	.957	.966	.969	.970	1.081	1.931
14	2.86	4.6	1.739	v. g.—	.621	.735	.819	.866	.902	.934	.958	.966	.967	.978	1.105	1.931
15	1.49	2.3	1.775	v. g.—	.621	.736	.815	.863	.899	.937	.958	.964	.966	.970	1.090	1.935
16	0.68	1.2	1.814	e.	.645	.740	.827	.862	.900	.928	.954	.963	.962	.969	1.080	1.960
17	0.68	1.0	1.813	v. g.+	.626	.733	.816	.861	.898	.926	.950	.970	.968	.972	1.075	1.951
18	0.97	1.7	1.815	v. g.	.634	.732	.805	.851	.886	.925	.949	.959	.961	.966	1.078	1.958
19	1.08	1.3	1.810	e.	.627	.742	.822	.863	.902	.930	.954	.964	.968	.973	1.073	1.943
21	3.31	8.7	1.706	e.	.627	.720	.806	.858	.901	.933	.957	.964	.965	.973	1.135	1.937
22	2.21	9.2	1.711	e.	.608	.713	.805	.851	.895	.925	.950	.959	.962	.967	1.132	1.938
26	0.96	1.6	1.800	e.—	.622	.732	.819	.856	.898	.932	.955	.968	.968	.973	1.082	1.950
27	1.38	1.9	1.768	e.—	.638	.727	.820	.864	.902	.933	.958	.969	.971	.975	1.087	1.924
28	1.29	1.0	1.824	e.	.623	.734	.815	.853	.896	.930	.956	.969	.968	.974	1.069	1.949
29	0.99	1.6	1.814	v. g.+	.616	.720	.803	.848	.886	.921	.951	.962	.963	.965	1.090	1.978
30	0.83	1.2	1.803	v. g.+	.614	.717	.803	.853	.874	.928	.959	.965	.969	.971	1.073	1.936
Oct. 1	0.89	1.2	1.853	v. g.+	.607	.720	.806	.849	.890	.921	.949	.961	.960	.967	1.075	1.992
2	1.10	2.0	1.804	e.—	.620	.732	.816	.850	.885	.922	.947	.957	.960	.965	1.071	1.932
3	0.73	1.2	1.806	e.	.616	.723	.809	.855	.891	.928	.954	.963	.966	.970	1.072	1.936
4	0.71	1.2	1.825	e.	.605	.721	.803	.848	.886	.920	.949	.959	.962	.968	1.064	1.942
5	0.73	1.2	1.822	v. g.	.628	.716	.804	.853	.891	.930	.949	.962	.967	.968	1.077	1.963
6	0.86	1.2	1.820	e.—	.627	.725	.808	.855	.897	.925	.949	.966	.965	.970	1.087	1.980
7	0.80	1.2	1.783	e.—	.628	.733	.816	.858	.903	.929	.957	.967	.969	.972	1.081	1.929
8	0.91	1.5	1.807	e.	.617	.728	.805	.853	.891	.924	.951	.962	.966	.969	1.076	1.945
9	0.76	1.5	1.784	e.—	.618	.713	.808	.851	.891	.922	.951	.963	.966	.970	1.085	1.941
10	0.81	1.9	1.801	v. g.+	.628	.733	.815	.862	.897	.925	.953	.964	.968	.970	1.082	1.950
11	0.95	4.0	1.703	v. g.	.615	.735	.803	.858	.895	.930	.953	.964	.966	.969	1.095	1.865
13	3.04	7.2	1.744	v. g.	.611	.714	.803	.855	.895	.925	.948	.962	.960	.964	1.118	1.901
14	3.21	7.0	1.770	g.+	.605	.719	.809	.865	.894	.924	.950	.959	.962	.962	1.100	1.946
15	1.94	7.7	1.758	g.—	.609	.717	.809	.855	.891	.926	.951	.960	.962	.962	1.113	1.957
16	3.05	6.1	1.765	g.—	.619	.713	.805	.850	.892	.925	.948	.959	.962	.965	1.100	1.941
17	2.62	6.2	1.764	v. g.	.608	.714	.806	.853	.891	.923	.949	.960	.961	.964	1.097	1.935
18	1.02	1.6	1.812	v. g.—	.614	.726	.807	.848	.890	.925	.949	.960	.960	.964	1.070	1.939
19	1.31	2.6	1.754	v. g.+	.617	.730	.817	.863	.898	.930	.957	.968	.968	.971	1.087	1.908
21	1.91	4.0	1.768	v. g.+	.631	.735	.820	.860	.902	.929	.955	.964	.965	.973	1.107	1.958
25	3.69	8.8	1.686	v. g.—	.613	.717	.805	.855	.897	.929	.955	.963	.966	.968	1.123	1.895
28	2.46	6.5	1.748	v. g.+	.613	.726	.817	.861	.900	.933	.956	.963	.965	.970	1.088	1.903
29	1.85	4.7	1.726	v. g.	.625	.728	.813	.852	.891	.925	.950	.960	.959	.965	1.117	1.928
30	1.83	4.4	1.755	g.	.616	.726	.812	.858	.900	.935	.953	.961	.968	.970	1.098	1.927
31	2.15	6.0	1.708	v. g.	.613	.721	.806	.860	.895	.927	.951	.966	.969	.967	1.113	1.901
Nov. 1	1.50	2.5	1.731	v. g.	.636	.740	.823	.871	.908	.940	.961	.973	.974	.977	1.083	1.876
5	2.74	4.9	1.721	v. g.—	.625	.728	.807	.855	.902	.929	.952	.966	.965	.968	1.116	1.921
6	1.86	4.5	1.716	g.	.617	.723	.815	.864	.899	.932	.953	.963	.966	.970	1.102	1.893
7	1.59	2.7	1.790	v. g.+	.622	.735	.817	.862	.897	.928	.957	.965	.966	.970	1.092	1.956
8	1.60	2.9	1.784	v. g.+	.612	.721	.795	.847	.888	.916	.944	.955	.960	.961	1.106	1.973
9	1.71	5.0	1.755	v. g.—	.622	.716	.793	.847	.886	.921	.949	.962	.958	.962	1.112	1.951
12	2.54	2.2	1.786	e.—	.622	.730	.814	.855	.898	.930	.952	.963	.964	.964	1.093	1.954
13	2.16	3.5	1.764	g.+	.625	.727	.801	.850	.896	.925	.947	.958	.960	.960	1.101	1.941
15	3.32	7.0	1.754	v. g.—	.598	.691	.778	.829	.877	.909	.938	.949	.949	.952	1.122	1.969
16	2.58	6.1	1.727	v. g.	.624	.725	.808	.848	.892	.926	.950	.960	.962	.967	1.113	1.924
17	2.25	4.9	1.727	e.	.621	.721	.804	.845	.887	.922	.946	.955	.957	.963	1.120	1.934
18	3.28	6.5	1.725	e.—	.627	.726	.811	.854	.893	.924	.948	.960	.961	.967	1.127	1.945
19	2.81	9.4	1.722	v. g.	.605	.708	.790	.839	.881	.906	.938	.949	.951	.954	1.127	1.940
20	3.95	11.7	1.738	e.—	.578	.677	.761	.801	.844	.871	.895	.910	.915	.916	1.130	1.975
21	3.52	7.0	1.755	v. g.—	.589	.692	.781	.831	.873	.907	.929	.938	.939	.940	1.108	1.945
22	3.30	6.0	1.767	e.—	.603	.703	.797	.840	.883	.910	.939	.949	.951	.955	1.110	1.962

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TABLE 42.—*Solar-constant values, Calama, Chile, 1918*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o	Bolometry. Atmospheric transmission for different wave lengths. Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610	Ratio E_o/A_o.	Solar constant E_o.
	mm.	*mm.*														
Nov. 23	3.54	6.0	1.760	v.g.—	0.598	0.703	0.791	0.827	0.875	0.902	0.931	0.944	0.949	0.948	1.120	1.972
25	4.42	11.1	1.763	e.—	.583	.690	.772	.822	.868	.897	.924	.938	.939	.946	1.135	2.002
26	3.12	12.5	1.706	v.g.—	.597	.702	.785	.829	.871	.904	.929	.939	.944	.945	1.134	1.936
27	2.57	5.1	1.725	v.g.	.618	.713	.800	.848	.886	.923	.951	.959	.958	.962	1.116	1.925
28	2.82	5.4	1.740	g.+	.618	.726	.809	.848	.896	.925	.949	.959	.961	.965	1.102	1.917
29	2.42	4.2	1.775	v.g.	.603	.714	.798	.848	.893	.921	.951	.958	.958	.965	1.105	1.962
30	1.98	5.0	1.745	v.g.+	.619	.732	.815	.862	.902	.929	.949	.958	.958	.965	1.103	1.926
Dec. 1	2.16	4.3	1.770	e.—	.627	.720	.803	.853	.892	.926	.947	.956	.961	.965	1.109	1.964
2	2.19	4.3	1.780	e.	.621	.722	.808	.853	.895	.928	.949	.965	.966	.969	1.097	1.954
3	1.70	3.3	1.780	e.	.610	.724	.808	.859	.899	.928	.954	.965	.966	.966	1.104	1.967
4	1.09	1.8	1.825	v.g.	.618	.722	.812	.854	.896	.925	.953	.962	.961	.969	1.095	1.999
5	2.82	3.1	1.833	g.—	.598	.710	.803	.833	.884	.914	.943	.947	.949	.954	1.084	1.986
6	3.28	[1] 4.5	1.722	p.+	.589	.706	.778	.827	.873	.910	.937	.944	.952	.955	1.133	1.954
7	2.66	7.0	1.760	e.—	.605	.701	.793	.832	.878	.910	.936	.947	.951	.952	1.126	1.983
8	3.28	13.0	1.690	e.	.588	.696	.784	.828	.872	.903	.928	.943	.943	.949	1.145	1.937
9	3.52	9.4	1.759	v.g.+	.580	.694	.788	.832	.881	.909	.934	.944	.949	.950	1.108	1.949
10	2.77	7.0	1.735	e.	.610	.713	.800	.844	.885	.912	.942	.952	.953	.958	1.133	1.949
11	1.92	4.2	1.760	e.	.620	.722	.805	.855	.892	.924	.953	.961	.962	.946	1.104	1.943
12	1.80	3.8	1.764	v.g.+	.612	.722	.808	.852	.895	.923	.950	.958	.961	.966	1.106	1.951
13	2.87	5.0	1.830	v.g.+	.576	.686	.778	.830	.871	.910	.938	.943	.945	.953	1.096	2.013
22	5.30	11.6	1.681	v.g.+	.600	.702	.792	.841	.891	.928	.950	.967	.970	.974	1.152	1.937
23	3.91	8.0	1.753	e.—	.608	.713	.802	.851	.896	.928	.954	.971	.969	.973	1.134	1.990
26	3.42	9.3	1.740	e.—	.592	.691	.788	.834	.886	.922	.951	.965	.970	.970	1.128	1.961
27	2.59	4.5	1.765	e.—	.609	.718	.812	.852	.896	.928	.960	.972	.971	.975	1.111	1.950
28	1.96	4.5	1.753	e.—	.618	.729	.821	.857	.905	.934	.961	.973	.973	.980	1.111	1.948
31	3.56	8.0	1.730	e.	.603	.709	.812	.858	.898	.933	.958	.972	.975	.979	1.122	1.942

[1] The precipitable water changed greatly.

TABLE 43.—*Solar-constant values, Calama, Chile, 1919.*

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o.	Bolometry. Atmospheric transmission for different wave lengths. Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610	Ratio $\frac{E_o}{A_o}$	Solar constant. E_o.	Solar constant. $\frac{E_o}{W.M.}$
	mm.	*mm.*															
Jan. 1	2.56	7.7	1.777	e.—	0.605	0.716	0.808	0.854	0.898	0.928	0.956	0.967	0.968	0.971	1.103	1.960	....
2	2.56	7.0	1.752	e.—	.608	.715	.804	.853	.899	.931	.953	.965	.970	.974	1.123	1.969	....
3	3.18	7.9	1.759	e.—	.602	.713	.803	.848	.896	.924	.951	.960	.962	.969	1.122	1.974	....
6	4.65	17.3	1.646	v.g.+	.594	.702	.801	.840	.886	.915	.940	.958	.960	.962	1.148	1.890	....
8	3.64	12.7	1.676	v.g.+	.587	.707	.798	.845	.897	.930	.951	.967	.965	.968	1.133	1.899	....
11	4.13	8.2	1.734	e.—	.595	.712	.806	.855	.899	.934	.959	.972	.973	.980	1.119	1.941	....
12	3.74	3.6	1.719	e.	.623	.744	.833	.875	.921	.950	.973	.983	.983	.986	1.098	1.888	....
14	2.50	2.1	1.830	v.g.—	.622	.738	.818	.868	.901	.939	.958	.970	.969	.975	1.072	1.963	....
16	4.41	10.9	1.722	e.—	.585	.696	.787	.841	.889	.921	.947	.956	.965	.968	1.131	1.948	....
17	3.90	8.4	1.730	v.g.—	.607	.714	.804	.851	.895	.927	.954	.962	.959	.961	1.121	1.939	....
18	3.06	5.4	1.771	v.g.	.608	.721	.817	.858	.904	.934	.959	.967	.971	.970	1.116	1.978	....
19	2.27	2.5	1.782	e.—	.602	.731	.825	.873	.914	.944	.966	.982	.980	.981	1.095	1.952	....
20	4.77	7.4	1.740	v.g.+	.598	.710	.805	.859	.901	.934	.962	.974	.972	.975	1.127	1.960	....
21	4.21	8.1	1.724	v.g.+	.596	.723	.805	.854	.895	.930	.961	.972	.973	.968	1.120	1.932	....
22	3.66	10.1	1.710	e.—	.596	.714	.801	.852	.898	.931	.956	.969	.968	.976	1.133	1.939	....
23	3.86	12.4	1.712	e.—	.593	.711	.805	.847	.896	.923	.949	.961	.963	.969	1.127	1.930	....
24	4.15	14.8	1.658	e.—	.599	.700	.791	.836	.888	.921	.949	.959	.965	.965	1.149	1.906	....
25	5.05	15.7	1.718	v.g.+	.555	.681	.769	.822	.872	.905	.933	.951	.953	.959	1.146	1.969	....
29	5.18	10.0	1.699	e.—	.600	.722	.815	.857	.900	.933	.958	.976	.972	.978	1.133	1.926	....

TABLE 43.—*Solar-constant values, Calama, Chile, 1919*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o.	Bolometry. Atmospheric transmission for different wave lengths. Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610	Ratio $\frac{E_o}{A_o}$	Solar constant. E_o.	E_o W.M.
	mm.	*mm.*															
Feb. 3	5.39	11.8	1.689	v.g.	0.608	0.726	0.812	0.861	0.900	0.935	0.958	0.969	0.974	0.969	1.153	1.949	....
6	3.93	13.4	1.708	e.—	.590	.701	.801	.852	.897	.932	.956	.971	.971	.974	1.139	1.946	....
7	3.64	7.1	1.728	e.—	.617	.722	.815	.863	.909	.940	.958	.968	.967	.975	1.117	1.931	....
8	3.19	4.8	1.798	v.g.	.605	.713	.808	.861	.901	.929	.958	.971	.974	.977	1.099	1.976	....
9	3.84	6.1	1.777	e.—	.611	.715	.807	.856	.901	.929	.953	.964	.966	.964	1.111	1.971	....
10	4.37	6.0	1.705	e.—	.602	.714	.807	.852	.890	.924	.952	.966	.969	.970	1.118	1.908	....
11	3.77	7.4	1.706	v.g.	.619	.731	.822	.872	.910	.940	.963	.976	.978	.978	1.118	1.909	....
12	5.77	11.5	1.715	v.g.—	.592	.706	.804	.846	.892	.927	.950	.959	.963	.969	1.144	1.961	....
13	6.08	13.2	1.724	v.g.+	.578	.693	.788	.837	.887	.917	.946	.960	.965	.967	1.135	1.957	....
14	6.57	10.2	1.742	v.g.—	.578	.695	.790	.841	.887	.919	.950	.958	.960	.969	1.121	1.952	....
15	7.18	13.4	1.690	v.g.—	.575	.691	.781	.825	.878	.906	.931	.939	.939	.940	1.133	1.915	....
16	6.40	11.8	1.705	v.g.—	.586	.692	.780	.831	.882	.909	.936	.948	.954	.954	1.139	1.944	....
17	4.99	9.5	1.765	e.—	.590	.712	.802	.851	.893	.929	.954	.969	.963	.969	1.118	1.973	....
18	4.96	7.4	1.725	v.g.	.606	.722	.803	.857	.903	.933	.959	.975	.974	.970	1.123	1.938	....
19	3.58	5.0	1.766	v.g.+	.609	.740	.823	.837	.906	.936	.959	.972	.969	.975	1.111	1.961	....
22	3.54	5.6	1.744	v.g.+	.616	.729	.822	.862	.908	.938	.963	.975	.975	.984	1.108	1.933	....
24	4.93	7.3	1.765	v.g.	.603	.720	.802	.851	.895	.924	.948	.958	.961	.967	1.118	1.974	....
25	3.54	6.7	1.709	v.g.+	.610	.723	.808	.861	.905	.939	.960	.973	.975	.980	1.132	1.936	....
26	3.22	7.8	1.703	e.	.606	.733	.814	.865	.901	.926	.961	.971	.973	.976	1.124	1.915	....
27	7.55	12.0	1.665	g.—	.600	.698	.786	.844	.886	.918	.944	.950	.951	.956	1.135	1.891	....
Mar. 1	7.47	18.6	1.709	v.g.—	.560	.630	.741	.771	.840	.884	.929	.944	.944	.952	1.143	1.952	....
3	5.97	10.9	1.696	v.g.	.591	.700	.806	.848	.896	.924	.957	.964	.969	.973	1.148	1.949	....
5	4.41	9.2	1.786	g.—	.582	.678	.791	.840	.888	.914	.941	.949	.950	.961	1.123	2.015	....
6	3.71	4.0	1.720	e.—	.604	.726	.812	.856	.903	.937	.957	.971	.970	.974	1.122	1.931	....
9	2.44	11.6	1.719	g.	.588	.692	.779	.828	.889	.916	.942	.964	.964	.969	1.127	1.938	....
10	2.98	8.3	1.731	v.g.—	.600	.711	.801	.844	.896	.925	.955	.969	.971	.979	1.107	1.916	....
13	4.32	9.8	1.685	p.+	.585	.708	.805	.845	.887	.918	.944	.959	.956	.964	1.175	1.981	....
17	5.29	12.4	1.700	v.g.—	.585	.697	.787	.837	.886	.921	.947	.965	.970	.972	1.121	1.905	....
18	3.51	6.8	1.751	v.g.—	.603	.703	.798	.851	.894	.928	.956	.971	.975	.977	1.113	1.949	....
19	3.79	9.1	1.726	v.g.+	.615	.718	.813	.855	.905	.933	.952	.970	.971	.970	1.120	1.934	....
21	6.23	11.8	1.656	v.g.+	.614	.712	.802	.852	.902	.934	.957	.973	.970	.973	1.141	1.897	....
25	3.79	11.5	1.713	v.g.+	.616	.709	.795	.849	.902	.934	.952	.968	.964	.969	1.133	1.942	....
26	2.88	5.5	1.743	e.—	.619	.722	.829	.868	.911	.941	.967	.982	.983	.983	1.111	1.938	....
28	3.09	5.5	1.742	v.g.+	.605	.717	.813	.861	.907	.934	.959	.971	.972	.975	1.121	1.955	....
30	4.67	12.6	1.705	v.g.+	.589	.688	.774	.843	.886	.919	.942	.959	.963	.967	1.139	1.942	....
31	5.23	13.3	1.658	v.g.+	.588	.696	.789	.844	.894	.921	.951	.960	.964	.968	1.154	1.913	....
Apr. 1	5.53	11.6	1.726	e.—	.597	.708	.807	.846	.895	.924	.950	.959	.958	.962	1.136	1.960	....
2	4.10	8.8	1.729	e.—	.604	.719	.806	.853	.897	.926	.953	.968	.975	.982	1.126	1.946	....
3	5.68	12.7	1.702	v.g.+	.591	.684	.774	.828	.883	.916	.944	.959	.967	.970	1.152	1.960	....
4	5.93	14.9	1.715	e.—	.553	.671	.758	.818	.871	.904	.934	.948	.951	.955	1.150	1.973	....
5	5.34	10.2	1.689	v.g.	.577	.703	.799	.852	.902	.929	.950	.969	.972	.972	1.148	1.938	....
6	3.66	8.5	1.690	v.g.+	.608	.726	.819	.854	.902	.933	.952	.964	.960	.964	1.144	1.933	....
7	3.47	6.7	1.728	v.g.+	.590	.712	.796	.852	.898	.934	.956	.971	.971	.979	1.123	1.940	....
8	3.08	5.5	1.777	e.—	.589	.715	.804	.852	.902	.930	.956	.975	.971	.980	1.104	1.962	....
9	2.37	3.3	1.764	v.g.	.611	.731	.830	.864	.910	.944	.959	.973	.974	.981	1.103	1.947	....
10	2.06	2.7	1.736	e.—	.613	.738	.830	.872	.916	.950	.966	.980	.980	.978	1.106	1.922	....
11	1.84	3.3	1.745	e.	.624	.739	.829	.873	.914	.944	.963	.977	.975	.977	1.103	1.925	....
12	3.20	8.0	1.718	v.g.	.592	.723	.913	.867	.911	.945	.965	.979	.976	.982	1.105	1.898	....
13	3.64	7.9	1.721	e.—	.609	.720	.821	.868	.906	.944	.963	.975	.970	.976	1.120	1.928	....
14	4.05	7.6	1.774	v.g.+	.589	.705	.804	.850	.896	.933	.956	.971	.970	.979	1.118	1.984	....
15	2.92	5.0	1.764	e.—	.607	.731	.821	.868	.907	.943	.962	.970	.969	.974	1.105	1.950	....
16	2.01	4.8	1.754	g.+	.615	.726	.818	.861	.897	.934	.958	.971	.975	.980	1.121	1.967	....
18	3.25	7.1	1.774	v.g.	.578	.694	.800	.846	.892	.924	.948	.963	.964	.968	1.124	1.994	....
19	3.12	8.3	1.744	v.g.+	.588	.702	.802	.848	.895	.935	.954	.971	.970	.982	1.129	1.970	....
22	5.54	12.0	1.735	g.+	.608	.711	.787	.853	.901	.927	.949	.961	.962	.972	1.155	2.004	....
23	3.63	3.8	1.741	v.g.+	.607	.725	.815	.874	.917	.939	.968	.979	.976	.980	1.103	1.920	....
24	1.69	3.0	1.732	e.	.632	.746	.836	.885	.924	.949	.974	.984	.980	.984	1.097	1.900	....
25	1.93	3.4	1.770	e.—	.635	.726	.833	.877	.914	.948	.969	.981	.976	.985	1.090	1.930	....
26	2.24	3.8	1.737	e.—	.613	.734	.831	.871	.916	.942	.967	.969	.977	.980	1.111	1.932	....

TABLE 43.—*Solar-constant values, Calama, Chile, 1919*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o.	Bolometry.											Ratio $\frac{E_o}{A_o}$	Solar constant.	
				Grade.	Atmospheric transmission for different wave lengths. μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610		E_o.	E_o W.M.
	mm.	*mm.*															
Apr. 27	1.85	3.7	1.770	e.—	0.610	0.736	0.823	0.868	0.914	0.944	0.962	0.976	0.974	0.983	1.103	1.953	......
28	1.72	2.6	1.808	e.—	.616	.738	.825	.871	.914	.946	.959	.968	.970	.975	1.089	1.969	......
29	1.60	3.6	1.765	e.	.610	.729	.821	.867	.909	.945	.964	.977	.981	.983	1.103	1.946	......
30	1.58	3.1	1.764	e.	.611	.729	.818	.873	.904	.944	.966	.974	.974	.980	1.101	1.943	......
May 1	1.58	2.2	1.790	e.—	.621	.738	.825	.872	.916	.945	.966	.979	.979	.984	1.090	1.952	......
2	1.36	2.4	1.788	e.—	.615	.730	.819	.866	.906	.938	.965	.977	.976	.980	1.092	1.952	......
3	1.43	2.4	1.737	v.g.+	.615	.742	.830	.873	.919	.944	.978	.979	.979	.986	1.089	1.893	......
4	1.36	1.8	1.794	e.	.632	.740	.821	.881	.921	.949	.966	.973	.976	.978	1.091	1.958	......
5	1.11	1.3	1.821	e.—	.646	.736	.834	.878	.914	.949	.968	.975	.976	.982	1.073	1.954	......
6	1.18	2.8	1.799	e.—	.627	.748	.824	.872	.913	.941	.968	.979	.975	.983	1.086	1.955	......
7	1.17	3.4	1.769	e.—	.621	.732	.827	.875	.913	.947	.969	.981	.979	.983	1.106	1.956	......
8	1.16	3.5	1.779	v.g.+	.624	.746	.829	.866	.910	.941	.965	.975	.972	.974	1.092	1.964	......
9	1.44	3.1	1.747	v.g.+	.623	.741	.828	.878	.920	.944	.971	.981	.979	.983	1.100	1.924	......
10	1.68	4.6	1.730	e.—	.605	.721	.823	.870	.912	.946	.969	.981	.981	.985	1.119	1.937	......
11	2.36	6.0	1.768	e.—	.598	.705	.805	.852	.894	.928	.956	.971	.968	.971	1.120	1.980	......
12	3.06	7.0	1.723	e.	.612	.719	.812	.864	.903	.934	.959	.975	.976	.981	1.117	1.924	......
13	3.32	8.1	1.703	g.+	.604	.738	.819	.862	.904	.941	.963	.971	.969	.974	1.117	1.901	......
14	3.88	10.7	1.707	g.	.601	.706	.793	.853	.901	.936	.953	.969	.970	.974	1.136	1.939	......
15	2.46	7.8	1.678	e.—	.618	.740	.824	.873	.917	.944	.970	.983	.979	.986	1.131	1.895	......
16	2.13	5.0	1.678	v.g.—	.621	.751	.834	.888	.922	.951	.976	.986	.981	.984	1.123	1.884	......
18	2.90	5.2	1.704	e.—	.625	.745	.830	.876	.916	.941	.968	.980	.977	.982	1.117	1.903	......
19	2.14	5.2	1.737	v.g.+	.632	.749	.831	.881	.918	.946	.969	.982	.976	.983	1.109	1.927	......
20	1.81	4.5	1.731	v.g.+	.619	.748	.831	.880	.925	.947	.972	.981	.979	.984	1.118	1.936	......
21	2.02	3.4	1.761	v.g.+	.637	.752	.833	.872	.915	.948	.968	.979	.984	.981	1.096	1.931	......
22	1.29	3.0	1.756	v.g.+	.602	.746	.833	.880	.914	.952	.970	.979	.982	.983	1.106	1.943	......
23	1.60	3.3	1.790	e.—	.602	.731	.821	.870	.913	.941	.962	.972	.978	.981	1.098	1.966	......
24	1.42	3.5	1.739	e.—	.605	.738	.830	.870	.923	.946	.971	.980	.981	.983	1.101	1.915	......
28	1.02	1.2	1.787	v.g.+	.610	.739	.824	.870	.916	.052	.073	.984	.984	.988	1.086	1.940	......
29	1.94	1.4	1.761	v.g.+	.603	.740	.834	.874	.925	.954	.972	.983	.978	.980	1.097	1.931	......
30	0.96	1.3	1.822	e.	.599	.728	.828	.876	.916	.940	.968	.972	.981	.988	1.083	1.975	......
31	0.78	....	1.781	e.—	.612	.750	.833	.870	.915	.948	.965	.977	.979	.979	1.098	1.956	......
June 1	0.85	2.4	1.752	v.g.—	.621	.737	.832	.878	.918	.943	.968	.981	.985	.986	1.122	1.962	......
2	2.48	4.3	1.718	e.—	.602	.735	.823	.877	.918	.951	.971	.983	.989	.986	1.105	1.898	......
3	1.81	1.1	1.754	e.—	.612	.740	.833	.874	.918	.955	.972	.979	.978	.983	1.102	1.933	......
4	0.63	1.1	1.805	e.—	.608	.726	.819	.866	.911	.940	.964	.982	.987	.985	1.101	1.989	......
5	0.76	1.1	1.760	e.	.616	.730	.822	.867	.913	.944	.968	.979	.978	.981	1.105	1.947	......
9	2.19	5.4	1.754	e.—	.615	.740	.840	.877	.914	.944	.964	.976	.971	.979	1.114	1.955	......
10	2.24	4.4	1.780	v.g.—	.615	.728	.813	.857	.896	.932	.954	.960	.968	.974	1.131	2.013	......
14	4.47	10.6	1.754	e.—	.600	.728	.828	.859	.903	.941	.960	.965	.964	.967	1.124	1.972	......
15	3.35	8.1	1.680	v.g.+	.616	.742	.824	.872	.916	.944	.970	.973	.974	.976	1.114	1.903	......
16	3.14	7.9	1.709	e.—	.611	.737	.828	.875	.917	.941	.969	.979	.977	.982	1.127	1.927	......
19	2.73	4.4	1.694	e.—	.608	.732	.829	.869	.917	.949	.971	.979	.979	.980	1.141	1.934	......
20	1.17	1.6	1.803	v.g.+	.622	.742	.824	.874	.906	.940	.966	.982	.980	.978	1.085	1.956	......
21	0.89	1.8	1.840	e.—	.620	.727	.819	.856	.904	.935	.956	.972	.970	.979	1.094	2.013	......
22	0.83	2.1	1.793	e.—	.622	.746	.833	.871	.910	.947	.963	.972	.975	.977	1.092	1.959	......
23	0.61	0.9	1.818	e.—	.620	.743	.832	.871	.908	.943	.964	.973	.972	.972	1.086	1.975	......
24	0.43	1.3	1.794	e.—	.640	.743	.832	.876	.921	.947	.969	.976	.974	.979	1.088	1.952	......
25	0.47	1.8	....	s.	.623	.734	.829	.874	.916	.944	.965	.977	.978	.980	....	....	1.955
26	1.39	1.3	....	s.	.626	.737	.832	.878	.919	.947	.966	.978	.979	.981	....	....	1.926
27	1.04	1.8	....	s.	.611	.732	.814	.861	.912	.940	.968	.977	.976	.978	....	....	1.938
28	1.28	2.0	....	s.	.621	.732	.827	.873	.915	.943	.964	.976	.977	.979	....	....	1.972
29	3.05	4.2	....	s.	.614	.724	.818	.864	.908	.938	.961	.974	.974	.977	....	....	1.969
30	3.16	2.7	....	s.	.610	.721	.815	.861	.905	.935	.960	.973	.973	.976	....	....	1.962
July 1	1.45	2.8	1.760	v.g.+	.638	.725	.809	.859	.898	.939	.969	.979	.978	.986	1.107	1.948	1.942
2	1.39	....	....	s.—	.616	.727	.821	.867	.910	.939	.962	.975	.975	.978	....	....	1.925
3	1.42	3.8	1.695	v.g.+	.623	.731	.818	.860	.907	.939	.968	.981	.982	.986	1.137	1.928	1.928
4	1.69	....	....	s.	.612	.725	.818	.865	.907	.939	.962	.973	.973	.977	....	....	1.980
6	1.93	....	....	s.	.619	.729	.824	.869	.912	.941	.963	.975	.976	.978	....	....	1.971
9	3.23	....	....	s.	.621	.731	.826	.872	.914	.942	.964	.976	.977	.979	....	....	1.954

TABLE 43.—*Solar-constant values, Calama, Chile, 1919*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o.	Bolometry. Atmospheric transmission for different wave lengths.											Ratio $\frac{E_o}{A_o}$	Solar constant.	
				Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610		E_o	E_o W.M.
	mm.	*mm.*															
July 10	0.92	3.7	....	s.	0.618	0.729	0.823	0.869	0.912	0.941	0.963	0.975	0.976	0.978	....	....	1.958
11	1.05	4.8	....	s.+	.616	.729	.822	.869	.910	.943	.964	.975	.974	.979	....	....	1.954
12	1.34	6.0	1.729	e.	.648	.752	.824	.869	.914	.949	.973	.975	.974	.981	1.117	1.932	1.951
13	1.39	3.9	....	s.	.623	.737	.829	.877	.917	.948	.967	.977	.977	.981	....	....	1.941
14	1.06	4.0	....	s.	.617	.731	.823	.870	.912	.944	.965	.975	.975	.979	....	....	1.965
15	0.93	2.4	....	s.	.622	.735	.827	.875	.915	.947	.966	.976	.976	.980	....	....	1.960
17	0.90	2.0	1.854	g.	.609	.729	.818	.853	.894	.932	.957	.968	.966	.973	1.056	1.957	1.959
18	0.74	4.7	1.732	v. g.+	.642	.738	.831	.873	.916	.946	.968	.979	.979	.981	1.126	1.951	1.972
19	1.77	6.6	....	s.	.613	.727	.819	.866	.908	.941	.963	.974	.974	.978	....	....	1.987
20	2.21	5.0	....	s.	.612	.725	.817	.864	.907	.939	.962	.973	.973	.977	....	....	1.961
21	1.75	4.2	1.730	e.	.617	.718	.816	.857	.902	.942	.967	.979	.984	.980	1.125	1.947	1.957
22	2.16	7.2	....	s.—	.606	.718	.811	.858	.902	.935	.959	.971	.971	.975	....	....	1.971
23	1.32	2.8	....	s.+	.620	.733	.825	.873	.913	.945	.966	.976	.976	.980	....	....	1.967
24	1.00	2.7	1.754	v. g.+	.642	.755	.831	.875	.913	.949	.969	.980	.981	.981	1.099	1.928	1.955
25	0.96	2.1	....	s.+	.620	.733	.826	.873	.914	.946	.966	.976	.976	.980	....	....	1.967
26	0.65	1.4	....	s.—	.612	.725	.818	.865	.907	.940	.963	.973	.973	.978	....	....	1.922
27	0.85	2.4	....	s.—	.614	.727	.819	.866	.908	.941	.963	.974	.974	.978	....	....	1.925
28	0.87	4.2	1.724	e.	.641	.734	.827	.863	.908	.941	.968	.979	.982	.983	1.133	1.959	1.959
29	2.07	....	....	s.—	.619	.729	.824	.869	.912	.941	.967	.975	.976	.978	....	....	1.958
30	1.73	6.3	....	s.	.615	.728	.821	.868	.909	.942	.964	.974	.974	.978	....	....	1.936
31	1.49	....	....	s.—	.620	.733	.825	.872	.913	.945	.966	.976	.975	.980	....	....	1.930
Aug. 1	0.92	2.6	1.731	e.	.639	.732	.824	.872	.908	.943	.971	.979	.979	.983	1.127	1.951	1.959
2	1.76	5.3	....	s.	.619	.732	.824	.872	.913	.940	.965	.976	.975	.980	....	....	1.943
3	3.00	8.0	....	s.	.608	.721	.814	.861	.904	.937	.961	.972	.972	.976	....	....	1.980
4	2.37	5.1	....	s.	.615	.728	.820	.867	.909	.941	.964	.974	.974	.978	....	....	1.959
5	1.64	5.0	1.748	v. g.—	.629	.734	.824	.862	.907	.942	.966	.976	.978	.980	1.107	1.936	1.963
6	1.16	5.3	....	s.	.605	.717	.810	.857	.901	.934	.959	.970	.970	.975	....	....	1.943
7	1.31	3.3	....	s.	.615	.727	.820	.867	.909	.941	.964	.974	.974	.978	....	....	1.962
8	1.34	2.2	1.788	e.—	.638	.740	.823	.860	.901	.937	.961	.977	.974	.979	1.100	1.967	1.961
9	1.87	2.7	....	s.	.615	.728	.820	.867	.909	.941	.964	.974	.974	.978	....	....	1.980
10	1.48	3.3	....	s.+	.616	.731	.823	.870	.912	.944	.965	.975	.974	.979	....	....	1.960
11	1.03	....	....	s.	.617	.728	.822	.867	.911	.940	.962	.975	.976	.978	....	....	1.939
13	1.13	3.5	1.738	g.+	.612	.711	.790	.836	.888	.923	.957	.970	.972	.976	1.114	1.937	1.924
14	3.12	....	....	u.—	.600	.711	.804	.850	.896	.927	.954	.967	.968	.971	....	....	1.946
15	1.56	3.2	....	s.—	.615	.729	.821	.868	.910	.942	.964	.975	.974	.979	....	....	1.950
16	1.65	2.5	....	u.+	.603	.714	.807	.854	.899	.930	.956	.969	.970	.972	....	....	1.932
17	2.15	4.9	....	s.	.603	.715	.806	.855	.899	.932	.957	.969	.969	.974	....	....	1.955
18	0.88	1.7	1.821	v. g.+	.640	.726	.815	.864	.903	.933	.964	.972	.973	.973	1.091	1.988	1.962
19	1.10	4.9	....	s.	.609	.722	.815	.862	.904	.937	.961	.972	.972	.976	....	....	1.927
20	1.97	5.0	....	s.	.614	.727	.820	.867	.909	.941	.963	.974	.974	.978	....	....	1.943
21	1.53	6.3	....	s.—	.613	.726	.819	.866	.908	.940	.963	.974	.973	.978	....	....	1.934
22	1.81	5.5	1.745	e.	.618	.727	.818	.862	.908	.942	.963	.979	.981	.983	1.122	1.959	1.966
23	1.95	2.9	....	s.	.617	.730	.822	.869	.911	.943	.964	.975	.975	.979	....	....	1.961
24	1.21	2.5	....	s.—	.607	.719	.812	.859	.902	.934	.960	.971	.971	.976	....	....	1.964
25	1.47	2.2	....	s.—	.614	.726	.819	.866	.908	.943	.963	.974	.974	.978	....	....	1.962
26	1.53	3.2	1.711	v. g.+	.655	.729	.820	.864	.902	.938	.964	.975	.976	.981	1.127	1.931	1.945
27	1.09	2.5	....	s.	.618	.731	.824	.871	.912	.944	.965	.975	.975	.980	....	....	1.954
28	1.05	1.9	....	s.	.620	.733	.825	.873	.914	.945	.966	.976	.976	.980	....	....	1.957
29	1.03	1.6	1.802	v. g.+	.633	.734	.818	.865	.901	.933	.962	.983	.979	.981	1.092	1.967	1.965
30	0.73	1.2	....	s.—	.619	.733	.825	.872	.913	.945	.966	.976	.976	.980	....	....	1.951
31	0.64	1.2	....	s.—	.619	.732	.824	.872	.913	.945	.965	.976	.975	.980	....	....	1.942
Sept. 1	0.57	1.7	....	s.—	.618	.728	.823	.869	.912	.940	.963	.975	.976	.978	....	....	1.937
2	0.60	2.1	....	s.—	.615	.728	.820	.867	.909	.942	.964	.974	.974	.978	....	....	1.918
3	2.24	4.0	....	u.+	.612	.725	.818	.865	.907	.938	.962	.973	.973	.977	....	....	1.934
4	1.51	4.6	1.734	e.—	.637	.730	.805	.858	.900	.933	.963	.978	.976	.981	1.119	1.941	1.946
5	1.55	3.6	....	s.	.612	.725	.818	.865	.907	.938	.962	.973	.973	.977	....	....	1.938
6	1.06	2.5	....	s.	.615	.728	.821	.868	.910	.941	.963	.974	.974	.978	....	....	1.946
7	0.67	1.6	....	s.	.618	.731	.824	.871	.912	.943	.964	.975	.975	.979	....	....	1.941
8	1.17	2.8	....	s.—	.614	.727	.820	.867	.909	.940	.963	.974	.974	.978	....	....	1.956

TABLE 43.—*Solar-constant values, Calama, Chile, 1919*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_0.	Bolometry.											Ratio $\frac{E_0}{A_0}$	Solar constant.	
				Atmospheric transmission for different wave lengths.													
				Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610		E_0.	E_0 W.M.
	mm.	*mm.*															
Sept. 9	1.00	3.7	1.726	v.g.—	0.637	0.710	0.810	0.855	0.901	0.934	0.958	0.974	0.972	0.976	1.124	1.941	1.937
10	1.20	3.4	....	s.	.609	.721	.814	.861	.904	.936	.960	.972	.972	.976	....	....	1.930
11	1.42	3.1	....	s.—	.614	.725	.819	.865	.908	.939	.962	.974	.975	.977	....	....	1.948
12	1.17	2.0	1.731	v.g.—	.664	.753	.834	.881	.912	.943	.968	.975	.978	.979	1.085	1.878	1.917
13	0.93	1.2	....	s.	.623	.736	.828	.876	.916	.946	.966	.977	.976	.981	....	....	1.956
14	1.27	2.0	....	s.	.615	.728	.820	.867	.909	.941	.963	.974	.974	.978	....	....	1.930
15	1.06	3.3	....	s.—	.608	.719	.812	.858	.903	.934	.959	.970	.972	.975	....	....	1.933
17	2.93	10.0	1.711	v.g.+	.615	.693	.797	.842	.892	.922	.955	.969	.974	.979	1.124	1.925	1.932
18	1.67	3.2	....	s.—	.612	.725	.817	.864	.907	.938	.962	.973	.973	.977	....	....	1.948
19	1.23	1.5	....	s.	.619	.731	.824	.872	.913	.944	.964	.976	.975	.980	....	....	1.957
20	1.27	2.7	1.721	v.g.+	.623	.716	.823	.869	.907	.936	.959	.969	.976	.976	1.130	1.947	1.957
21	1.25	1.9	....	s.—	.615	.726	.820	.866	.909	.939	.963	.974	.975	.977	....	....	1.957
22	2.23	5.3	....	s.	.605	.717	.810	.857	.901	.933	.958	.970	.970	.975	....	....	1.925
23	1.35	5.6	1.766	v.g.	.624	.708	.804	.835	.886	.915	.952	.958	.960	.971	1.108	1.958	1.941
25	2.67	5.7	....	s.—	.606	.717	.811	.858	.901	.934	.958	.970	.970	.975	....	....	1.928
26	0.95	1.8	1.768	v.g.+	.627	.723	.819	.861	.903	.940	.964	.976	.976	.978	1.103	1.951	1.957
27	1.24	3.0	....	s.—	.607	.720	.813	.860	.908	.935	.959	.971	.971	.976	....	....	1.928
28	1.10	1.9	....	s.—	.613	.725	.818	.865	.908	.939	.962	.974	.973	.978	....	....	1.938
29	1.09	2.4	....	s.	.600	.711	.804	.851	.896	.929	.955	.968	.968	.972	....	....	1.935
30	1.37	4.5	....	s.—	.607	.718	.812	.857	.902	.933	.959	.971	.972	.974	....	....	1.926
Oct. 2	3.72	12.9	1.668	g.+	.623	.733	.813	.859	.907	.943	.959	.969	.972	.973	1.165	1.944	....
7	1.65	11.3	1.649	v.g.	.598	.692	.790	.839	.891	.931	.961	.971	.968	.970	1.144	1.887	1.898
8	1.91	6.7	....	s.	.613	.725	.818	.865	.908	.940	.962	.974	.973	.978	....	....	1.971
9	1.86	7.2	....	s.	.609	.722	.815	.862	.904	.936	.960	.972	.972	.976	....	....	1.957
10	2.05	7.7	1.691	v.g.	.628	.724	.816	.865	.903	.935	.963	.971	.972	.976	1.137	1.924	1.961
11	2.31	7.7	....	s.	.597	.707	.800	.847	.893	.926	.952	.965	.965	.970	....	....	1.948
12	2.95	8.3	....	u.+	.578	.682	.774	.824	.875	.906	.929	.946	.947	.953	....	....	1.918
13	2.42	6.0	....	s.—	.597	.708	.801	.848	.893	.926	.953	.966	.966	.971	....	....	1.945
14	1.62	2.8	....	s.	.621	.734	.827	.874	.915	.945	.965	.976	.976	.980	....	....	1.952
15	1.33	2.6	1.790	v.g.+	.631	.733	.813	.857	.903	.942	.955	.970	.970	.976	1.106	1.979	1.968
17	2.59	....	....	s.—	.606	.717	.810	.856	.901	.932	.958	.970	.971	.974	....	....	1.939
19	1.78	4.6	....	s.—	.608	.720	.813	.860	.903	.935	.960	.972	.972	.976	....	....	1.960
20	1.82	5.4	....	s.+	.606	.718	.811	.858	.901	.934	.959	.971	.971	.975	....	....	1.962
21	1.91	5.9	1.785	v.g.+	.628	.726	.808	.851	.900	.935	.964	.973	.977	.979	1.102	1.968	1.972
23	1.98	5.2	....	s.	.613	.724	.818	.864	.908	.938	.962	.974	.974	.977	....	....	1.946
24	1.91	5.1	1.775	g.	.607	.693	.794	.832	.874	.914	.947	.961	.964	.970	1.109	1.970	1.959
25	2.32	6.1	....	s.—	.604	.715	.808	.855	.900	.931	.957	.970	.970	.973	....	....	1.968
26	2.24	6.5	....	s.	.595	.705	.798	.846	.891	.924	.951	.964	.964	.969	....	....	1.964
28	2.55	4.0	....	s.—	.609	.720	.816	.860	.904	.935	.960	.972	.973	.975	....	....	1.964
31	1.50	2.6	....	s.—	.598	.709	.801	.847	.893	.925	.951	.966	.966	.970	....	....	1.954
Nov. 1	1.89	2.5	....	s.—	.607	.720	.813	.860	.903	.935	.959	.971	.971	.976	....	....	1.964
2	1.17	1.6	....	s.	.614	.725	.819	.864	.907	.939	.967	.974	.974	.978	....	....	1.958
3	1.89	2.8	....	s.—	.612	.723	.817	.862	.906	.937	.961	.973	.973	.977	....	....	1.958
4	1.89	1.7	....	s.—	.613	.724	.818	.864	.907	.938	.961	.974	.974	.978	....	....	1.961
5	1.63	2.5	1.800	v.g.+	.633	.738	.825	.862	.901	.935	.958	.971	.977	.975	1.087	1.956	1.973
6	2.61	2.3	....	s.—	.600	.712	.804	.850	.895	.927	.954	.967	.968	.972	....	....	1.949
7	1.46	1.2	....	s.	.616	.728	.821	.868	.910	.941	.963	.975	.974	.979	....	....	1.953
9	4.58	2.9	....	s.—	.614	.724	.818	.864	.907	.939	.962	.974	.974	.978	....	....	1.949
10	2.88	3.8	1.763	e.—	.637	.723	.815	.864	.901	.935	.966	.973	.974	.975	1.106	1.950	1.960
11	2.64	5.1	....	s.—	.596	.708	.800	.846	.892	.924	.951	.965	.965	.970	....	....	1.960
12	2.41	5.5	....	s.	.598	.709	.802	.849	.894	.927	.953	.966	.966	.971	....	....	1.957
13	2.90	6.0	....	s.	.596	.707	.799	.846	.892	.924	.951	.965	.965	.970	....	....	1.953
15	2.97	7.0	....	s.	.597	.708	.801	.848	.893	.927	.953	.966	.966	.970	....	....	1.941
17	2.34	4.7	1.714	e.—	.618	.715	.815	.862	.905	.937	.963	.977	.981	.977	1.115	1.911	1.929
18	2.45	5.2	....	s.	.606	.718	.811	.858	.902	.934	.959	.971	.971	.975	....	....	1.968
21	3.43	6.8	....	s.	.600	.711	.803	.850	.894	.927	.954	.967	.967	.972	....	....	1.952
22	3.03	5.5	....	s.—	.599	.710	.803	.849	.894	.927	.953	.967	.967	.971	....	....	1.940
23	2.84	5.5	....	s.+	.596	.707	.799	.846	.891	.924	.951	.965	.965	.969	....	....	1.945
24	3.34	6.4	....	s.—	.593	.705	.797	.843	.889	.922	.949	.963	.963	.968	....	....	1.942

TABLE 43.—*Solar-constant values, Calama, Chile, 1919*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o.	Bolometry. Atmospheric transmission for different wave lengths. Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610	Ratio $\frac{E_o}{A_o}$	Solar constant. E_o.	Solar constant. E_o W.M.
	mm.	mm.															
Nov. 25	4.45	6.2	....	s.—	0.604	0.715	0.808	0.854	0.898	0.930	0.956	0.969	0.970	0.974	....	....	1.943
26	2.97	4.9	....	s.—	.605	.716	.809	.855	.899	.931	.957	.970	.970	.974	....	....	1.968
27	2.44	6.7	1.734	v.g.	.610	.714	.799	.845	.890	.923	.954	.959	.961	.961	1.103	1.913	1.928
28	2.89	4.5	....	s.	.600	.712	.804	.851	.895	.928	.954	.968	.968	.972	....	....	1.956
29	1.56	2.9	....	s.	.603	.715	.808	.854	.898	.930	.956	.969	.970	.974	....	....	1.952
30	2.17	3.3	....	s.	.606	.717	.811	.856	.901	.933	.958	.971	.971	.975	....	....	1.958
Dec. 1	2.78	3.8	....	s.	.604	.715	.808	.854	.898	.930	.957	.969	.970	.974	....	....	1.958
3	3.88	4.4	....	s.	.597	.708	.800	.847	.892	.924	.952	.965	.966	.970	....	....	1.951
5	2.79	6.5	1.726	e.—	.602	.716	.804	.849	.894	.926	.954	.970	.967	.970	1.123	1.938	1.952
6	3.44	14.0	....	s.—	.571	.679	.771	.819	.874	.899	.920	.937	.937	.944	....	....	1.925
7	3.69	13.2	....	s.—	.575	.686	.778	.826	.877	.908	.930	.945	.945	.951	....	....	1.927
8	4.55	10.5	....	s.+	.583	.694	.785	.833	.882	.913	.939	.954	.954	.959	....	....	1.928
9	4.89	6.0	....	u.+	.601	.713	.805	.852	.896	.928	.955	.968	.968	.972	....	....	1.963
10	4.10	8.1	....	s.—	.586	.697	.788	.836	.884	.915	.942	.957	.957	.962	....	....	1.945
12	4.26	8.5	1.707	v.g.+	.612	.711	.807	.848	.901	.934	.960	.969	.969	.973	1.128	1.926	1.951
15	6.38	22.7	....	s.—	.564	.674	.767	.815	.873	.900	.913	.929	.928	.935	....	....	1.954
16	8.01	23.0	....	s.—	.576	.687	.779	.827	.878	.908	.931	.947	.946	.952	....	....	1.937
17	6.76	18.0	1.681	g.	.573	.658	.755	.816	.874	.914	.946	.958	.963	.964	1.181	1.940	1.951
18	6.53	19.8	....	s.—	.580	.690	.781	.829	.880	.909	.934	.950	.950	.955	....	....	1.968
19	7.03	13.0	....	s.—	.588	.700	.791	.839	.886	.918	.945	.959	.959	.964	....	....	1.946
20	5.30	....	....	s.—	.589	.701	.792	.839	.886	.918	.945	.960	.960	.965	....	....	1.938
21	3.86	9.3	....	s.—	.590	.702	.793	.840	.887	.919	.946	.961	.961	.965	....	....	1.939
22	4.00	11.0	1.711	v.g.+	.598	.688	.778	.828	.871	.900	.934	.945	.944	.951	1.144	1.959	1.955
23	3.82	13.0	1.714	e.—	.582	.690	.779	.817	.867	.898	.928	.941	.944	.947	1.147	1.967	1.951
24	3.81	11.2	1.716	v.g.—	.606	.713	.817	.856	.887	.923	.949	.961	.966	.968	1.126	1.932	1.959
25	4.96	16.9	....	u.+	.575	.685	.776	.824	.877	.904	.928	.944	.944	.950	....	....	1.965
26	5.45	18.1	1.706	v.g.	.566	.654	.753	.802	.850	.885	.913	.922	.927	.935	1.165	1.987	....
28	6.52	21.4	....	u.+	.573	.682	.774	.822	.875	.902	.925	.941	.941	.947	....	....	1.974
29	7.83	20.6	....	u.+	.575	.686	.778	.826	.877	.903	.930	.945	.945	.951	....	....	1.957
31	6.19	20.6	1.684	g.	.595	.679	.780	.830	.874	.903	.936	.941	.943	.950	1.166	1.964	1.967

TABLE 44.—*Solar-constant values, Calama, Chile, 1920.*

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o.	Bolometry. Atmospheric transmission for different wave lengths. Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610	Ratio $\frac{E_o}{A_o}$	Solar constant. E_o.	Solar constant. E_o W.M.
	mm.	mm.															
Jan. 2	5.14	7.2	1.731	e.—	0.611	0.723	0.791	0.853	0.898	0.929	0.958	0.965	0.966	0.972	1.138	1.971	1.969
3	4.66	8.8	....	s.—	.592	.703	.795	.842	.888	.921	.948	.962	.962	.967	....	....	1.967
4	4.47	7.0	....	s.	.598	.709	.801	.848	.893	.926	.953	.966	.967	.971	....	....	1.960
5	4.75	2.6	....	s.—	.598	.710	.802	.848	.893	.925	.953	.966	.966	.971	....	....	1.960
7	5.13	17.9	....	u.+	.578	.688	.780	.828	.879	.908	.932	.948	.948	.954	....	....	1.949
10	4.46	20.3	....	u.+	.580	.690	.782	.829	.880	.910	.935	.950	.950	.956	....	....	2.002
11	5.84	24.0	....	u.+	.568	.678	.771	.819	.875	.893	.919	.935	.934	.941	....	....	1.975
12	9.03	24.4	....	s.—	.571	.681	.774	.822	.876	.898	.924	.940	.939	.946	....	....	1.950
14	7.56	14.5	....	u.+	.594	.706	.797	.844	.890	.922	.950	.963	.964	.968	....	....	1.956
15	5.95	20.0	....	u.+	.566	.674	.766	.814	.872	.893	.913	.930	.930	.937	....	....	1.984
17	7.91	22.0	....	u.+	.565	.672	.765	.813	.871	.891	.910	.927	.927	.935	....	....	1.987
18	8.44	20.2	....	u.+	.569	.677	.769	.817	.873	.896	.917	.934	.934	.941	....	....	1.963
19	7.53	18.0	1.697	g.	.595	.709	.789	.834	.881	.914	.941	.950	.953	.958	1.153	1.956	1.978
20	7.51	21.0	....	u.+	.564	.674	.768	.816	.873	.889	.914	.930	.929	.936	....	....	1.946
21	7.54	22.2	....	u.	.573	.676	.767	.813	.866	.882	.910	.924	.927	.931	....	....	1.929

TABLE 44.—*Solar-constant values, Calama, Chile, 1920*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_0.	Bolometry.											Ratio $\frac{E_0}{A_0}$	Solar constant.	
				Grade.	Atmospheric transmission for different wave lengths.												
					μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610		E_0	E_0 W. M.
	mm.	*mm.*															
Jan. 22	8.97	23.6	....	u.+	0.583	0.691	0.783	0.829	0.878	0.906	0.935	0.946	0.948	0.955	....	....	1.963
23	7.15	19.4	....	s.	.587	.697	.788	.834	.883	.913	.940	.954	.955	.960	....	....	1.986
24	7.10	20.9	....	s.—	.581	.689	.780	.826	.877	.903	.931	.945	.947	.952	....	....	1.973
25	6.78	17.2	1.667	v.g.—	.592	.684	.785	.838	.884	.920	.953	.965	.964	.965	1.178	1.957	1.961
26	7.52	19.1	....	s.—	.588	.698	.790	.837	.884	.914	.942	.952	.954	.961	....	....	1.948
27	6.62	20.6	....	s.	.587	.697	.789	.835	.883	.914	.941	.954	.956	.961	....	....	1.959
28	5.21	19.6	....	s.	.589	.699	.791	.837	.885	.916	.943	.956	.958	.963	....	....	1.957
29	8.89	23.9	....	u.+	.575	.680	.771	.817	.870	.890	.919	.932	.935	.939	....	....	1.959
30	7.32	24.0	....	s.—	.581	.688	.779	.825	.876	.901	.931	.942	.944	.950	....	....	1.968
31	8.32	22.3	....	s—.	.576	.683	.774	.820	.872	.894	.922	.936	.938	.943	....	....	1.949
Feb. 6	9.56	29.6	....	u.+	.581	.688	.779	.826	.876	.902	.932	.943	.945	.951	....	....	1.963
7	8.42	26.5	....	u.+	.573	.676	.768	.813	.867	.883	.911	.925	.928	.932	....	....	1.931
8	9.28	24.4	....	s.—	.579	.685	.776	.823	.874	.898	.928	.939	.942	.947	....	....	1.945
9	7.70	19.9	....	s.	.578	.686	.777	.823	.874	.897	.926	.940	.942	.947	....	....	1.960
10	7.18	16.2	1.718	v.g.+	.590	.679	.768	.821	.874	.904	.946	.956	.960	.963	1.166	2.009	1.992
11	6.53	12.0	....	s.—	.591	.703	.795	.841	.889	.920	.947	.960	.962	.966	....	....	1.953
12	7.92	10.8	....	u.+	.592	.704	.795	.842	.888	.920	.947	.957	.959	.965	....	....	1.969
13	7.70	16.3	....	u.+	.580	.687	.778	.825	.875	.901	.930	.941	.944	.950	....	....	1.955
14	6.01	18.9	....	s.	.577	.685	.776	.822	.873	.897	.925	.939	.941	.946	....	....	1.932
15	7.50	17.5	....	s.—	.582	.689	.780	.827	.877	.903	.932	.944	.946	.952	....	....	1.942
16	5.85	16.5	....	s.	.583	.693	.784	.830	.879	.907	.935	.949	.951	.955	....	....	1.953
18	6.61	17.6	....	s.—	.583	.692	.783	.829	.879	.906	.935	.948	.950	.955	....	....	1.961
19	5.78	16.2	....	s.—	.583	.692	.784	.830	.879	.909	.937	.951	.952	.958	....	....	1.959
20	5.37	12.1	....	s.—	.590	.701	.792	.838	.886	.918	.945	.958	.959	.964	....	....	1.967
24	8.42	16.9	....	s.—	.587	.697	.788	.835	.882	.912	.940	.950	.952	.959	....	....	1.957
25	6.52	17.7	1.705	e.—	.580	.683	.777	.825	.878	.911	.941	.954	.960	.961	1.157	1.973	1.969
26	6.49	18.0	....	u.+	.581	.689	.780	.826	.876	.904	.932	.947	.947	.953	....	....	1.954
27	7.62	16.0	....	s.—	.588	.698	.789	.836	.883	.913	.941	.952	.954	.961	....	....	1.958
28	9.07	14.8	....	s.—	.590	.700	.792	.839	.885	.916	.944	.954	.956	.962	....	....	1.943
Mar. 1	8.86	23.2	....	s.—	.579	.685	.776	.822	.873	.897	.927	.939	.941	.947	....	....	1.973
2	7.33	22.8	....	s.	.579	.687	.778	.824	.875	.899	.928	.941	.944	.948	....	....	1.979
3	8.66	21.5	....	s.—	.574	.677	.768	.814	.867	.883	.913	.926	.929	.933	....	....	1.957
5	8.69	21.3	....	s.—	.586	.697	.788	.835	.882	.912	.940	.950	.953	.959	....	....	1.939
6	8.61	21.6	....	u.+	.582	.690	.781	.828	.878	.905	.934	.945	.947	.953	....	....	1.964
7	9.56	20.8	....	s.—	.588	.698	.790	.837	.884	.914	.942	.952	.955	.961	....	....	1.961
8	8.47	22.7	....	s.—	.584	.693	.784	.831	.880	.908	.936	.947	.950	.956	....	....	1.946
10	6.36	15.1	....	s.	.591	.701	.793	.840	.886	.917	.945	.955	.957	.964	....	....	1.950
11	6.09	13.0	1.697	e.—	.596	.701	.800	.841	.891	.922	.958	.969	.974	.973	1.156	1.961	1.961
11[1]	6.02	....	1.678	e.—	.608	.709	.802	.849	.897	.929	.957	.963	.969	.972	1.164	1.954	1.963
12	6.63	17.6	....	s.—	.586	.697	.788	.834	.883	.913	.940	.954	.955	.960	....	....	1.961
13	6.03	15.6	....	s.	.588	.698	.790	.836	.884	.917	.943	.958	.958	.963	....	....	1.945
14	4.99	12.4	1.683	v.g.	.592	.706	.792	.846	.901	.938	.956	.969	.968	.973	1.148	1.932	1.953
15	4.29	10.4	....	s.	.597	.707	.800	.847	.893	.926	.953	.965	.965	.970	....	....	1.969
16	5.67	12.0	....	s.	.591	.702	.795	.841	.888	.920	.947	.960	.961	.966	....	....	1.956
17	6.44	14.2	1.672	e.—	.589	.691	.779	.833	.881	.912	.948	.959	.969	.970	1.155	1.931	1.943
18	6.60	12.3	....	s.	.586	.696	.787	.834	.882	.914	.941	.955	.956	.961	....	....	1.936
19	6.71	14.0	....	s.—	.585	.694	.785	.832	.880	.909	.938	.948	.950	.957	....	....	1.930
20	7.42	13.1	....	s.—	.588	.697	.789	.836	.883	.913	.941	.950	.953	.960	....	....	1.922
21	6.23	17.1	....	s.—	.579	.687	.778	.824	.874	.900	.929	.944	.944	.951	....	....	1.920
22	8.83	21.4	....	s.—	.576	.682	.772	.819	.871	.892	.922	.934	.937	.942	....	....	1.923
23	8.37	17.5	....	u.	.576	.683	.774	.820	.872	.894	.922	.936	.938	.943	....	....	1.846
24	7.19	18.5	....	s.—	.580	.688	.779	.825	.875	.901	.930	.943	.945	.950	....	....	1.887
26	7.61	18.8	....	s.	.583	.692	.783	.829	.879	.906	.935	.948	.950	.955	....	....	1.934
27	3.55	....	1.744	e.—	.616	.718	.815	.855	.906	.932	.965	.973	.975	.975	1.128	1.967	1.969
28	3.01	4.1	....	s.—	.613	.726	.819	.866	.908	.939	.962	.974	.973	.978	....	....	1.967
29	3.18	8.4	1.721	e.—	.619	.725	.812	.854	.904	.936	.960	.975	.975	.976	1.135	1.953	1.969
30	3.77	6.9	1.765	v.g.	.609	.705	.810	.851	.907	.940	.969	.975	.975	.976	1.092	1.924	1.948
31	3.18	8.3	1.752	v.g.—	.608	.708	.798	.845	.895	.929	.958	.970	.974	.974	1.1175	1.959	1.954

[1] Afternoon observation.

TABLE 44.—*Solar-constant values, Calama, Chile, 1920*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_0.	Bolometry.											Ratio $\frac{E_0}{A_0}$	Solar constant.	
				Atmospheric transmission for different wave lengths.													
				Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610		E_0.	E_0 W. M.
	mm.	*mm.*															
Apr. 1	3.91	1.1	1.704	e.—	0.603	0.708	0.798	0.842	0.891	0.924	0.952	0.964	0.965	0.972	1.137	1.937	1.938
2	4.39	5.5	....	s.	.593	.703	.796	.844	.890	.923	.950	.963	.963	.968	....	....	1.953
3	3.67	9.0	....	s.—	.600	.712	.804	.851	.895	.928	.954	.967	.968	.972	....	....	1.955
4	3.48	6.3	....	s.—	.603	.715	.808	.855	.899	.932	.957	.969	.969	.974	....	....	1.969
5	3.23	5.0	....	s.—	.602	.713	.806	.853	.898	.931	.956	.968	.969	.973	....	....	1.961
6	2.36	5.3	1.740	g.+	.603	.697	.791	.838	.890	.922	.951	.963	.964	.971	1.116	1.942	1.923
7	2.70	4.9	....	s.	.611	.723	.817	.863	.906	.938	.961	.973	.973	.977	....	....	1.923
8	2.79	4.7	....	s.	.608	.720	.813	.860	.903	.936	.960	.972	.972	.976	....	....	1.934
9	3.25	6.4	1.758	e.	.603	.710	.797	.848	.898	.929	.964	.971	.974	.978	1.117	1.965	1.964
10	3.67	5.0	1.744	e.—	.611	.721	.814	.866	.910	.933	.961	.971	.979	.974	1.123	1.960	1.965
11	2.76	2.9	....	s.	.617	.728	.823	.868	.911	.941	.964	.975	.976	.979	....	....	1.962
12	3.69	7.2	....	s.—	.604	.715	.808	.855	.899	.931	.956	.969	.970	.974	....	....	1.956
13	3.18	6.0	1.756	v.g.—	.613	.710	.809	.854	.902	.934	.956	.966	.972	.973	1.120	1.967	1.959
14	2.69	3.6	1.762	e.	.626	.733	.825	.864	.909	.937	.965	.974	.978	.978	1.108	1.954	1.960
15	2.52	4.1	....	s.—	.608	.721	.814	.861	.904	.936	.960	.972	.972	.976	....	....	1.953
16	2.87	4.4	....	s.—	.607	.719	.812	.859	.903	.935	.959	.971	.971	.976	....	....	1.954
17	2.98	6.8	....	g.+	.590	.696	.798	.832	.883	.915	.951	.960	.964	.966	....	....	1.953
18	4.16	7.7	....	s.	.601	.712	.805	.852	.897	.930	.956	.968	.968	.973	....	....	1.957
19	3.89	8.9	1.739	e.	.609	.706	.798	.845	.898	.924	.959	.973	.975	.975	1.122	1.950	1.950
20	3.66	7.7	....	s.	.602	.713	.807	.853	.898	.931	.956	.969	.969	.973	....	....	1.961
21	4.38	8.8	....	s.—	.596	.707	.800	.847	.893	.926	.952	.965	.965	.970	....	....	1.933
22	3.81	5.6	1.735	v.g.—	.610	.715	.815	.856	.906	.934	.965	.969	.973	.976	1.115	1.935	1.953
23	2.92	6.8	....	s.—	.604	.716	.809	.856	.900	.932	.958	.976	.970	.974	....	....	1.950
24	3.44	5.6	....	s.	.609	.720	.814	.860	.903	.935	.959	.970	.971	.977	....	....	1.949
25	2.97	9.2	....	s.	.598	.709	.802	.849	.895	.908	.954	.966	.967	.971	....	....	1.947
26	3.03	7.0	1.731	v.g.+	.614	.720	.813	.858	.903	.938	.967	.974	.973	.980	1.128	1.953	1.963
27	2.93	7.6	....	v.g.+	.610	.722	.815	.862	.905	.937	.961	.972	.972	.977	....	....	1.955
28	3.94	11.4	....	s.—	.599	.710	.803	.850	.894	.926	.953	.963	.964	.971	....	....	1.939
29	3.33	7.0	....	s.	.608	.720	.813	.859	.903	.934	.959	.971	.972	.976	....	....	1.976
30	3.50	5.8	....	s.—	.602	.713	.806	.852	.897	.929	.955	.965	.967	.973	....	....	1.959
May 1	4.10	6.1	....	s.—	.609	.720	.814	.859	.903	.935	.959	.970	.971	.976	....	....	1.934
2	2.04	2.4	....	s.	.617	.730	.823	.870	.912	.942	.964	.975	.975	.979	....	....	1.957
3	1.88	3.0	1.764	v.g.+	.624	.731	.813	.853	.901	.935	.962	.974	.979	.975	1.124	1.983	1.965
4	1.72	4.8	....	s.	.613	.726	.819	.865	.908	.939	.962	.974	.973	.978	....	....	1.962
5	1.91	3.6	....	u.+	.609	.721	.814	.861	.904	.936	.960	.972	.972	.976	....	....	1.945
6	1.73	3.7	....	u.+	.620	.732	.825	.872	.913	.944	.965	.976	.976	.980	....	....	1.951
7	2.27	4.0	....	g.+	.614	.727	.818	.866	.909	.940	.963	.974	.974	.978	....	....	1.955
8	3.21	2.8	....	s.—	.619	.732	.825	.872	.913	.944	.964	.976	.975	.980	....	....	1.965
9	2.21	5.5	....	s.—	.614	.724	.819	.864	.907	.938	.962	.974	.975	.978	....	....	1.923
10	2.30	4.6	....	u.+	.611	.723	.816	.863	.906	.938	.961	.973	.973	.977	....	....	1.941
11	1.55	2.7	1.791	e.—	.629	.735	.828	.870	.911	.943	.961	.974	.975	.983	1.099	1.969	1.971
12	1.60	2.8	....	s.	.618	.731	.823	.870	.912	.943	.964	.975	.975	.979	....	....	1.962
13	1.21	3.1	....	s.—	.612	.723	.817	.863	.906	.937	.961	.973	.974	.977	....	....	1.963
14	1.85	6.0	1.736	p.+	.595	.717	.811	.823	.885	.911	.946	.956	.967	.972	1.137	1.974	1.952
16	2.37	4.6	....	s.	.616	.729	.822	.869	.910	.942	.963	.975	.975	.978	....	....	1.963
17	1.58	3.0	....	u.+	.613	.726	.818	.866	.908	.939	.962	.974	.973	.978	....	....	1.952
19	2.75	8.7	....	s.	.601	.712	.805	.852	.896	.929	.955	.967	.968	.972	....	....	1.959
20	2.36	2.3	1.792	v.g.+	.632	.729	.830	.874	.912	.944	.961	.970	.976	.971	1.097	1.966	1.964
21	1.02	1.6	....	s.—	.615	.728	.821	.868	.910	.941	.963	.975	.974	.978	....	....	1.936
22	1.25	2.9	....	s.—	.612	.724	.817	.864	.907	.938	.962	.973	.973	.977	....	....	1.939
23	1.07	1.8	....	s.—	.620	.733	.826	.873	.914	.946	.965	.976	.976	.980	....	....	1.942
24	2.00	3.8	....	s.—	.612	.723	.817	.862	.907	.937	.961	.973	.974	.978	....	....	1.942
25	1.82	4.6	....	s.	.614	.725	.819	.865	.907	.939	.962	.974	.975	.978	....	....	1.970
26	1.27	3.6	....	u.+	.612	.724	.817	.865	.907	.938	.962	.973	.973	.977	....	....	1.921
27	1.19	1.4	....	s.	.622	.735	.828	.875	.916	.946	.966	.976	.976	.980	....	....	1.964
28	1.02	1.8	....	s.	.619	.731	.824	.871	.913	.944	.965	.975	.975	.979	....	....	1.952
29	0.83	1.7	....	s.—	.615	.727	.821	.867	.909	.940	.963	.975	.975	.979	....	....	1.942
30	0 75	1.3	1.817	v.g.	.643	.734	.822	.862	.914	.931	.967	.974	.975	.979	1.105	2.008	1.986
31	0.79	1.3	....	s.—	.620	.732	.826	.872	.913	.944	.965	.976	.977	.980	....	....	1.952

TABLE 44.—*Solar-constant values, Calama, Chile, 1920*—Continued.

Date.	Pressure water vapor.	Precipitable water.	Apparent solar constant A_o.	Bolometry.											Ratio $\frac{E_o}{A_o}$	Solar constant.	
				Atmospheric transmission for different wave lengths.													
				Grade.	μ 0.355	μ 0.403	μ 0.460	μ 0.511	μ 0.637	μ 0.702	μ 0.830	μ 1.008	μ 1.244	μ 1.610		E_o.	$\frac{E_o}{W. M.}$
	mm.	*mm.*															
June 1	0.85	2.6	....	s.—	0.619	0.731	0.825	0.870	0.912	0.943	0.963	0.976	0.976	0.980	....	....	1.937
2	1.08	1.0	1.781	e.	.659	.746	.834	.875	.918	.941	.965	.976	.980	.981	1.084	1.931	1.942
3	0.53	1.1	....	s.—	.623	.736	.828	.876	.916	.946	.967	.977	.977	.980	....	....	1.968
4	0.67	1.4	....	s.—	.618	.729	.823	.869	.911	.941	.964	.975	.976	.979	....	....	1.929
5	0.71	2.1	....	s.	.622	.735	.827	.874	.915	.946	.965	.976	.976	.980	....	....	1.960
6	0.66	3.5	....	s.	.619	.732	.825	.872	.913	.946	.964	.976	.975	.979	....	....	1.951
7	1.55	4.2	....	s.—	.618	.731	.824	.871	.912	.945	.965	.975	.975	.979	....	....	1.938
8	1.66	3.4	....	s.—	.620	.732	.826	.872	.913	.944	.965	.975	.976	.980	....	....	1.929
9	1.52	1.5	....	s.	.621	.738	.832	.878	.918	.949	.967	.978	.978	.982	....	....	1.940
10	0.81	0.7	....	s.	.628	.740	.834	.880	.920	.950	.967	.979	.979	.982	....	....	1.933
11	0.86	0.8	....	s.	.628	.740	.834	.879	.919	.949	.967	.978	.979	.982	....	....	1.943
12	0.54	1.4	....	s.	.620	.733	.826	.873	.914	.945	.966	.976	.976	.980	....	....	1.924
13	0.56	2.0	....	s.	.621	.732	.827	.872	.914	.945	.965	.976	.977	.978	....	....	1.939
14	1.16	4.0	....	s.	.616	.727	.821	.867	.909	.940	.963	.975	.975	.979	....	....	1.917
15	1.92	4.0	....	s.	.619	.732	.825	.872	.913	.945	.965	.976	.975	.980	....	....	1.929
18	2.88	6.2	....	s.—	.621	.732	.827	.873	.914	.944	.965	.977	.977	.980	....	....	1.941
19	2.60	4.4	....	s.	.618	.730	.824	.869	.911	.943	.964	.975	.977	.981	....	....	1.942
23	3.46	3.6	....	s.	.614	.725	.819	.865	.907	.938	.962	.974	.975	.978	....	....	1.947
24	1.69	1.8	1.771	v.g.+	.628	.743	.828	.874	.899	.950	.970	.984	.980	.983	1.091	1.932	1.942
25	1.22	4.8	....	s.—	.615	.728	.821	.868	.910	.941	.963	.974	.974	.978	....	....	1.921
26	1.75	5.0	....	s.—	.618	.731	.824	.871	.912	.943	.964	.975	.975	.979	....	....	1.951
27	2.63	8.0	....	s.—	.611	.722	.816	.861	.904	.936	.960	.973	.973	.977	....	....	1.925
30	2.86	4.6	1.731	v.g.	.624	.716	.819	.862	.906	.948	.966	.979	.982	.981	1.112	1.924	1.939
July 1	0.82	0.9	....	s.—	.623	.736	.829	.876	.917	.946	.966	.977	.977	.981	....	....	1.944
2	0.66	0.7	....	s.	.624	.737	.830	.877	.917	.947	.966	.977	.977	.981	....	....	1.949
3	0.45	1.5	....	s.—	.621	.733	.826	.873	.914	.945	.965	.976	.976	.980	....	....	1.935
4	1.28	1.7	....	s.—	.623	.734	.829	.874	.915	.945	.966	.977	.978	.981	....	....	1.948
5	0.98	1.4	....	s.	.621	.734	.826	.874	.915	.945	.965	.976	.976	.980	....	....	1.955
6	1.80	2.1	....	s.—	.621	.732	.826	.872	.913	.944	.965	.977	.978	.982	....	....	1.948
7	0.67	2.6	....	s.	.620	.733	.825	.873	.914	.944	.965	.976	.976	.980	....	....	1.948
8	0.51	1.2	....	s.—	.623	.735	.829	.875	.916	.946	.966	.977	.978	.981	....	....	1.951
9	0.88	1.8	....	s.	.622	.733	.827	.873	.914	.944	.965	.977	.977	.981	....	....	1.944
10	0.79	2.1	....	s.	.612	.723	.817	.863	.906	.937	.961	.973	.974	.977	....	....	1.932
11	1.53	2.3	....	s.—	.610	.721	.815	.860	.904	.935	.960	.972	.973	.977	....	....	1.945
12	2.84	2.8	....	s.—	.614	.727	.819	.866	.908	.940	.963	.974	.974	.978	....	....	1.944
15	4.94	9.9	....	s.—	.612	.724	.817	.864	.906	.938	.961	.975	.974	.978	....	....	1.933
18	2.61	5.9	....	s.—	.614	.727	.820	.867	.909	.940	.963	.974	.974	.978	....	....	1.933
19	2.43	....	....	s.—	.613	.726	.819	.866	.908	.940	.963	.974	.974	.978	....	....	1.932
20	1.87	6.2	....	s.	.616	.729	.822	.869	.911	.942	.963	.975	.975	.979	....	....	1.950
21	1.98	8.4	....	s.—	.611	.724	.817	.864	.904	.938	.961	.973	.973	.977	....	....	1.965
22	5.74	6.2	....	s.—	.614	.705	.819	.864	.907	.939	.962	.973	.974	.979	....	....	1.947
24	2.07	4.7	....	s.—	.617	.728	.822	.867	.910	.941	.963	.975	.976	.979	....	....	1.950
25	4.58	3.4	....	s.—	.619	.730	.825	.870	.913	.942	.964	.976	.976	.980	....	....	1.943
26	1.42	1.8	....	s.—	.617	.729	.823	.868	.910	.941	.964	.975	.976	.979	....	....	1.950

NOTES ON HUMP MOUNTAIN WORK.

Although, as we have said, the observations at Hump Mountain, North Carolina, are not worth much as evidence in regard to the variability of the sun, on account of the unfavorable sky conditions which usually prevailed there, there were occasionally days in which the sky appeared to be as satisfactory as anywhere. The average of the somewhat discordant values obtained at Hump Mountain is possibly 1 per cent lower than the average which would have probably prevailed during the same months had the observations been made at the Calama station. This probably indicates that a correction for residual influence of water vapor ought to be applied to these North Carolina observations, but owing to their inferior weight as evidence of the solar variability it has not been thought worth while to apply such a correction.

The Hump Mountain observations have their principal value from the fact that some of them were taken at lower temperatures than any other complete solar-constant observations which have ever been made. In particular we call attention to the observations of January 12, 1918, when the work was carried through at a temperature below the zero of the Fahrenheit scale. The observations with the wet and dry thermometer, indeed, ran so low that the available meteorological tables did not give adequate information to reduce them. These observations are as follows:

Time	h m 7 25	h m 9 23	h m 9 45	h m 10 17	h m 12 18
Dry bulb C	−21.2	−19.3	−18.4	−18.4	−16.8
Wet bulb C	−21.7	−19.8	−18.9	−18.8	−17.4

Under these circumstances the solar-constant value, 1.958, of grade V.G.− was obtained. The sky is stated to have been cloudless with the exception of very small floating cumuli near the northern horizon. The value obtained is not at all exceptional, but tends to widen in a very notable way the range of circumstances under which solar-constant observations have been taken without calling doubt upon the accuracy of the method. The observer at the pyrheliometer froze both his hands and feet in the course of these observations.

Chapter V.

DISCUSSION OF THE ERRORS OF SOLAR CONSTANT OBSERVATIONS.

In Volume II of these Annals, Chapters I and IV, we discussed the theory and sources of error of our methods of determining the solar constant of radiation as then practiced. Fundamentally there is little to change in that discussion, but experience has led to changes in procedure in certain respects in the application of the high and low sun methods of observing. Moreover a new brief method depending on measurements of brightness of the sky around the sun has been employed latterly in South America. Finally, the general view which we can now take of numerous solar-constant observations made over a period of nearly 20 years leads to modifications.

If our work had for its sole object to determine an average value of the solar constant of radiation, the large number of observations which have been made at stations ranging in elevation from sea level to 4,420 meters, in humidity and temperature from the coastal conditions of a Washington summer to those of the Atacama desert in midwinter, and even including at Hump Mountain days of observation when the thermometer stood below zero of the Fahrenheit scale, all this profusion of observations under diverse circumstances, fortified as it is by reasonable theory, and further by the results of balloon pyrheliometry described in the appendix, would long ago have satisfied us.

But unfortunately the work has shown that the sun is variable. Others have found that these solar variations seem to be of consequence for meteorology. It has become, therefore, our duty and purpose to determine the individual daily values of the solar constant to a degree of accuracy sufficient to give a fair view of the sun's variation. For this purpose, individual day's errors of 1 per cent become serious blemishes. We must, therefore, try to determine whether such errors as this are generally excluded in the long series of values here given, and what improvements, if any, experience dictates.

1. ERRORS OF PYRHELIOMETRY.

Evidence has already been given tending to show that our scale of pyrheliometry has been preserved to within 1 per cent over the long period of years involved. What more immediately concerns us now is to determine the probable accidental error of the results of the pyrheliometry for a given day relative to neighboring days. To be more definite, a day's solar-constant determination by the long method rests nowadays on 12 or more individual observations, half on one pyrheliometer, half on another. A day's determination by the short method based, as is usual, on three separate observations also rests usually on 12 such pyrheliometer observations, half on one pyrheliometer, half on another. Let us first estimate the probable error of a single pyrheliometer observation, reserving to a final summary the discussion of the pyrheliometric part of the error of a complete day.

On a preceding page has been given the ratio of the readings of the copper-disk pyrheliometers A. P. O. IV and A. P. O. VII, as read on Mount Wilson in 1920. These instruments have both been employed there in the same way for solar-constant work ever since 1908. In the comparison just referred to, the instruments were not read simultaneously, but one minute of time apart at high sun. Hence whatever their average deviation, it is in part due to such variations of the sky as occurred in this one minute by which the readings were separated. From this comparison. the average deviation of the two instruments is 0.62 per cent. Hence the probable error of a single observation of one instrument is approximately $\frac{0.84\times0.62}{\sqrt{2}}$ or 0.37 per cent, a value which, for the reason given above, is doubtless in excess rather than defect.

From data taken from a similar comparison made at Montezuma, Chile, in 1921, between silver-disk pyrheliometers S. I. 30 and S. I. 29, which are daily employed there, the average deviation of these instruments (also read at high sun one minute apart) is 0.34 per cent. Whence the probable error of one observation on one silver-disk pyrheliometer is approximately $\frac{0.84\times0.34}{\sqrt{2}}$ or 0.20 per cent, including as before the probable error due to variation of the sky in one minute.

In each case the comparisons are scattered over a period of a good many days so that we may regard the result as containing all of the elements of error which are apt to affect the observations.

2. SOURCES OF ERROR WITH THE SPECTROBOLOMETER.

We shall follow here for a time the same course as in Annals, Volume II, page 77 et seq., and thus we shall consider first:

CHANGE OF SENSITIVENESS DURING OBSERVATION.

Great improvement has been made in the conditions treated of under this heading in Volume II of these Annals. The changes which we then thought might be due to terrestrial magnetic changes, proved to be due largely to the incompleteness of our spectrum, limited as it was up to July, 1909, by the use of a flint-glass prism nearly opaque for wave lengths less than 0.38 micron. Ever since that date we have been using an ultra-violet crown glass prism with stellite or silvered glass mirrors, and have observed the spectrum from 0.34 to 2.44 microns in wave length. Beyond these limits we have investigated by special methods in our expeditions to Mount Whitney, and have determined as well as we can the corrections to account for the ultra-violet and infra-red regions not observed. With these new conditions first fully introduced in the year 1911, the correction factors determined from changes of the ratio of pyrheliometer reading to bolographic area are much smaller. Here is a random lot for five good Mount Wilson days of 1920. The values are in percentages.

Bolograph	I.	II.	III.	IV.	V.	VI.
Correcting factors	+0.9	−0.3	−0.7	−0.3	+0.3	0.0
	+0.4	−0.9	0.0	+0.5	−0.4	+0.5
	−1.8	−0.7	+0.2	+0.4	0.0	+2.0
	+2.0	0.0	−1.2	−0.9	−1.2	+1.4
	−0.2	+0.2	0.0	−0.9	+0.2	−0.9

Here is a similar set from Calama observations of 1920:

Bolograph	I.	II.	III.	IV.	V.	VI.
Correcting factors	+0.5	−1.2	−0.5	+0.5	+0.3	+0.8
	−2.3	−0.3	−0.1	0.0	+0.6	+1.9
	−1.0	−0.4	−1.3	+0.7	+1.2	+1.3
	−1.5	−0.8	−0.6	+0.9	+1.1	+0.8
	−0.8	−1.1	−0.1	+0.7	+1.3	0.0

From the figures given it appears that the range of correcting factors at both stations is of the order of 3 per cent. The Mount Wilson values appear to run in no regular order. The Calama values exhibit a tendency to yield larger bolographic areas as compared to the pyrheliometer readings at the larger air masses.

We have made tests of pyrheliometers read in different positions, and with different exposures of sky around the sun, but (at such solar altitudes as we observe) without finding either that the altitude of the sun or the brightness of the sky (seen by the pyrheliometer but not by the bolometer) tended appreciably to modify these corrections. They seem to be mainly inherent in the bolographic work.

There are many probable sources of error in the production of energy curves.

1. Unequal reflection at the coelostat mirrors due to dust, to varying angle of exposure, or to shifting of the beam to surfaces unequally bright. We have made it a point to dust the mirrors before each run. Mr. Aldrich made a considerable number of experiments with two pyrheliometers, one read direct, the other by reflection of the solar rays at the coelostat in positions suited to high and low sun. A very large number of comparisons of this kind would be necessary to fix definitely so small an error as that due to change of reflection with angle at the coelostat. No clear evidence of such a change was found, but it is not absolutely excluded.

2. Imperfect following on the sun. We are accustomed to follow by means of a pinhole solar image cast at about 3 meters distance. Deviations of following from side to side cause the solar beam to pass through different thicknesses of glass at the prism. Deviations vertically alter the distribution on the bolometer which, owing to heat conduction, rapidly decreases in sensitiveness toward the ends of the strips. Mr. Aldrich made many experiments on this and found that, with our ordinary care in following, changes as great as 1 per cent in the bolometric response were likely to occur several times in a single bolograph. Greater care in following is now being practiced.

3. Changes of temperature by altering the resistances of the strips of the bolometer, and of the coils of the galvanometer, it is certain, must produce changes of sensitiveness.

4. Magnetic changes due to the daily variations of the earth's field and changes of temperature of the magnets must alter sensitiveness.

5. Inequalities of the galvanometer scale. This defect was undervalued in our discussion in Volume II of these Annals. If the galvanometer scale progressively changes in sensitiveness toward larger deflections, then since the bolometric curves are shifted by 1 or 2 centimeters each to each, to avoid their crossing upon the photographic plate, they would not be strictly comparable even if of equal heights. But in all parts of the spectrum, and especially toward shorter wave lengths, considerable changes of ordinates occur from curve to curve. Hence it occurs that inequalities of galvanometer scale sensitiveness are bound to be seriously objectionable. In all recent years we have frequently tested the galvanometer scale and these inequalities have seldom much exceeded 2 per cent in the length of the scale. Still they may sometimes have had some influence.

6. Errors of omission of spectrum regions. In theory we require the complete energy curves with all their bands and lines, extending from zero to infinite wave lengths to compare with the pyrheliometry. In practice the ultra-violet beyond 0.34 micron and infra-red beyond 2.4 microns are cut off. Allowances for these nonobserved parts are made to the best of our knowledge, but admittedly imperfectly. Readers will see by reference to Volume III of these Annals, page 40, that the omission of much more important regions of spectrum than we now omit, while it greatly increased the range of correcting factors, demonstrably altered scarcely at all the solar-constant values. Yet without the correcting factors the error would have been fatal.

7. Errors of determining bolographic areas. Time would fail if we were to attempt to measure every detailed bit of area of every curve. There is no planimeter in existence suitable to give the areas with high enough accuracy. The curves are full of ragged detail due to the Fraunhofer lines and terrestrial bands. Our procedure is to draw with ink a mean smooth curve representing the actual curve

as well as may be and by measuring the ordinates to the smooth curves at nearly 40 places we determine the total area by summation. These areas must be corrected for absorption of the optical system, but such corrections being in the same proportions for all curves of each day introduce no incomparability. What is less satisfactory, each smooth curve must interpolate for long stretches of spectrum over the great water-vapor bands of the infra-red, and the great solar bands of the blue and violet. Furthermore the areas of the water-vapor bands must be determined and subtracted from the smooth-curve areas. The zero line of the curves is found by drawing straight lines connecting the traces formed by inserting shutters once in one minute or longer intervals. These connecting lines run often from 10 to 20 centimeters between their defining traces, during which interval one can only imagine the possible wanderings of the real zero. The average ordinates of the bolographic curves do not exceed 70 millimeters, and are defined by the smooth curves and zero lines above described. One can not reasonably hope the probable error of a single ordinate measurement under these circumstances is less than 1 per cent. Accordingly for an area depending on the sum of 38 such ordinates the probable error would be assigned as $\frac{1}{\sqrt{38}}$ or 0.16 per cent if the individual errors can be regarded as independent. Since it is probable that several ordinates in succession are apt to be altered in the same sense if the zero line is defective, we shall do well to estimate this source of probable error a little larger and will take it as 0.2 per cent. With this assumption determinations of the areas of individual curves may occasionally be nearly or quite 1 per cent in error from cause No. 7 alone.

8. Errors in determining areas of infra-red bands. These bands, whose areas must be subtracted from the smooth-curve areas range from 8 to 25 per cent of the areas remaining after their removal. The first figure would sometimes occur at high sun on a very dry day, the second figure at low sun on a day of exceptional humidity. From such data as we have, we believe that these total band areas have been determined by us to a probable error of approximately 1.5 per cent. If this value is admitted it corresponds to from 0.12 to 0.38 per cent of the total areas. Accordingly, errors nearly reaching 1 per cent may occasionally occur from errors in measuring band areas.

All of the preceding eight sources of error tend to make the ordinates of the bolographic curves of a single day not comparable. Some of the defects are general over the entire spectrum, others affect small sections only. But on the whole their gross effect tends to be eliminated when the ordinates of each curve are altered throughout in the percentage given by the pyrheliometric correcting factors. So far as the pyrheliometry is itself in error, one determination relative to another through the day, the correcting factors introduce errors instead of removing them. The probable error of the mean of a pair of pyrheliometer readings such as each correcting factor is based upon appears to be $\frac{0.37}{\sqrt{2}}=0.26$ per cent for Mount Wilson and $\frac{0.20}{\sqrt{2}}=0.14$ per cent for Calama. Hence errors of 1 per cent and 0.6 per cent for individual curves may occasionally be introduced thereby at the two respective stations.

We believe ourselves justified in the conclusion that the primarily bolometric errors are removed to within limits of usually less than half a per cent for each curve as a whole by the scheme of correcting factors, but occasionally short portions of individual curves may easily be erroneous by several per cent by poor following, irregular drift, or variations of atmospheric transparency.

TABLE 45.—*Departures from Bouguer formula of bolometric observations.*

Mount Wilson, Calif.,[1] observations, Sept. 20, 1914.								Calama, Chile, observations, Aug. 1, 1919.						
Actual ordinates, bolograph V.	Percentage deviations.						Plaee.	Actual ordinates, bolograph I.	Percentage deviations.					
	V.	VI.	VII.	VIII.	X.	XI.			I.	II.	III.	IV.	V.	VI.
mm.								*mm.*						
7.2	+ 2.3	− 2.3	−3.5	+2.3	+1.6	−0.5	−23	7.6	+ 0.5	0.0	−0.9	0.0	0.0	+ 0.5
15.8	0.0	− 3.5	−2.8	+2.3	+1.6	−1.2	22	13.6	+ 0.5	−2.3	+4.2	−0.5	−0.9	− 0.5
9.0	−20.2	−12.2	+2.3	0.0	−2.3	0.0	21	23.4	+ 0.5	−1.1	+0.2	+0.2	−0.5	− 2.1
15.2	+10.2	− 7.2	0.0	−2.3	+2.3	+1.2	20	40.0	0.0	−0.2	−0.7	+0.9	0.0	0.0
35.0	0.0	+ 1.2	−6.7	0.0	+1.2	0.0	19	23.4	+ 2.1	+0.5	−0.7	0.0	0.0	− 1.4
21.0	− 8.4	− 2.3	0.0	0.0	+1.2	0.0	18	43.7	− 0.7	0.0	+1.9	0.0	+0.9	− 1.9
32.3	− 1.2	0.0	0.0	+4.7	0.0	0.0	17	61.2	− 1.1	+0.5	+0.7	−0.7	+0.5	− 3.5
56.2	0.0	− 0.7	0.0	0.0	0.0	+2.3	16	30.5	0.0	+0.2	+0.2	+0.2	−1.1	+ 0.2
26.8	− 0.9	+ 3.3	0.0	−0.7	0.0	0.0	15	47.0	− 3.0	+0.2	−0.5	+0.5	0.0	+ 3.0
36.9	+ 0.5	+ 0.9	+0.2	+1.4	−1.9	−0.7	14	65.0	− 0.9	0.0	+0.9	0.0	−0.2	0.0
49.7	− 0.7	− 0.5	−0.5	+0.7	−0.5	−0.9	13	27.4	0.0	0.0	0.0	−0.2	−0.7	+ 1.6
61.8	− 2.1	− 1.2	0.0	+0.9	+1.9	+1.6	12	37.0	0.0	+0.2	−0.7	−0.5	0.0	+ 0.9
70.8	− 2.3	− 0.9	0.0	+0.7	+0.9	+0.7	11½	......	......	......	......	......	......	......
80.4	− 2.1	− 1.4	0.0	+0.9	−0.5	+0.7	11	50.0	+ 2.3	−0.2	−0.7	−0.2	+0.2	+ 1.1
95.0	− 0.5	− 1.9	−0.2	0.0	0.0	+0.5	10½	......	......	......	......	......	......	......
109.6	0.0	0.0	+0.2	+0.2	0.0	0.0	10	69.0	+ 0.7	−0.7	+0.2	−0.7	0.0	+ 0.9
117.6	+ 0.2	0.0	+0.5	−0.2	−0.2	−0.2	9½	77.1	+ 0.2	−0.2	+0.2	−0.9	−0.2	0.0
120.8	+ 0.5	+ 0.5	−0.2	+0.5	−0.5	−0.2	9	83.2	0.0	+0.9	−0.2	−1.1	0.0	+ 0.2
119.2	+ 0.5	+ 0.5	0.0	+0.7	−0.9	−0.9	8½	87.1	0.0	+1.1	0.0	−0.5	0.0	+ 0.7
115.8	+ 0.7	+ 0.5	0.0	+0.9	−0.9	−0.9	8	88.2	0.0	+0.7	−0.7	−0.7	−0.2	+ 0.7
110.8	+ 0.9	+ 0.2	−0.2	0.0	+1.4	−1.9	7½	86.0	− 0.5	+0.5	0.0	−0.5	−0.2	+ 0.7
103.0	+ 0.5	− 0.5	−0.5	+0.9	−1.4	−1.6	7	80.9	− 1.4	+0.5	0.0	0.0	0.0	+ 1.6
92.0	− 0.9	− 0.7	+0.5	0.0	0.0	−0.5	6½	76.0	− 0.2	+0.2	−0.2	−0.5	0.0	+ 0.5
81.9	+ 1.4	0.0	+0.5	0.0	−0.9	0.0	6	69.8	− 0.5	0.0	−0.2	+0.5	0.0	+ 0.5
72.2	+ 0.5	− 0.5	0.0	0.0	−1.6	0.0	5½	63.7	− 0.5	0.0	−0.2	+0.5	−0.2	+ 0.2
65.0	+ 1.4	− 1.6	0.0	−0.5	+0.2	−1.4	5	57.8	− 0.2	0.0	+0.2	+0.2	−0.9	0.0
58.0	+ 1.6	− 0.7	−0.2	−0.7	+1.4	−3.0	4½	51.9	+ 0.5	0.0	−0.2	0.0	+1.1	− 1.4
52.0	+ 1.4	− 0.7	+0.5	−0.5	+2.3	−4.2	4	46.3	+ 0.2	−0.5	+0.5	+0.2	−0.7	+ 0.2
46.5	+ 1.6	0.0	0.0	−0.5	+0.9	−0.9	3½	40.5	+ 0.7	−0.9	+0.5	+0.9	−1.1	0.0
126.8	+ 1.4	+ 0.5	0.0	−1.4	0.0	−3.5	3	99.5	+ 1.9	0.0	0.0	+1.6	−0.2	− 0.2
113.0	+ 0.9	+ 0.2	+0.2	−0.9	0.0	−2.8	2½	89.9	+ 1.9	−1.1	−0.7	+0.9	−0.2	0.0
99.2	+ 0.7	0.0	0.0	−1.2	0.0	−3.3	2	80.4	+ 2.6	0.0	0.0	+1.1	0.0	0.0
72.0	+ 0.5	0.0	−0.2	−1.6	+0.5	−1.9	1	61.1	+ 1.6	−0.9	−1.4	+0.7	0.0	+ 0.2
44.2	+ 0.2	+ 0.2	0.0	−0.2	+1.6	−0.5	0	41.7	+11.1	0.0	−1.4	0.0	−0.2	− 0.2
67.0	− 2.1	+ 0.9	−0.2	−0.5	+0.5	−0.5	+ 1	22.3	+ 8.6	0.0	−4.0	−2.3	+0.5	0.0
35.0	0.0	− 0.2	−0.9	−1.6	+2.8	+2.3	2	10.4	0.0	+4.5	−5.7	−6.6	0.0	+14.0
21.0	− 0.9	+ 0.9	−3.3	+1.9	+5.0	0.0	3							
Mean...	1.9	1.3	0.7	0.9	1.0	1.1	....	Mean ..	1.3	0.5	0.8	0.7	0.3	1.1

[1] As these deviations are taken from straight lines drawn to represent the whole work of this morning, including four other curves, they are slightly larger than if lines were fitted to these bolographs only.

As fair examples of the outstanding local errors in bolographic ordinates remaining after the pyrheliometric corrections have been applied, we now give the actual deviations in percentages of the various corrected ordinates from the straight lines of extrapolation of the logarithmic transmission plots. These residuals contain both the experimental errors and the errors due to changes in sky transparency. In order to avoid unfair impressions of inferior accuracy in certain of the less intense regions of the spectrum, we give the actual ordinates in millimeters as originally read from one of the bolographs. We have selected the last six curves of September 20, 1914, to represent Mount Wilson, and all curves of August 1, 1919, to represent Calama.

POSITION OF THE RECORDING SPOT ON THE GALVANOMETER SCALE.

The influence of inequalities of sensitiveness of the galvanometer scale has already been treated. It is one of the many sources of error which are approximately but not exactly eliminated by the pyrheliometric correcting factors. We have kept this inequality of sensitiveness to such small limits during the period covered by this report that we feel safe in saying the device just named has practically wholly eliminated errors caused thereby.

ABSORPTION OF THE OPTICAL APPARATUS.

This subject was treated fully at page 78 of Volume II of these Annals. It was shown that the uncertainty in knowledge of its effects corresponded to a probable error of 0.14 per cent in the early work. Our present knowledge of instrumental absorption is so much better than it was then that there can be no doubt that this source of error is now negligible. Furthermore, it is not a variable from curve to curve, and so could in any event be neglected for present considerations.

FORM OF THE ENERGY CURVE OUTSIDE THE ATMOSPHERE.

This subject is treated at page 80 of Volume II of these Annals. Our present conditions do not much alter the conclusions reached there. For long method values at Calama we find a probable error of 0.12 per cent for the solar constant caused by errors of the bolographic ordinates. The value stated there, 0.17 per cent, seems still fairly applicable to Mount Wilson values in view of the table of deviations just given.

FINAL PROBABLE ERROR OF A SOLAR-CONSTANT DETERMINATION BY THE LONG METHOD.

The formulae for this subject are given at page 81 of Volume II of these Annals. We shall, however, omit the determination of the probable error of the absolute value of the solar constant there given, which involves the discussion of standard pyrheliometry. We are concerned now with relative values from day to day. With the error measures as given above, the probable error for a representative long method "solar-constant" value determined at Mount Wilson is

$$\sqrt{\frac{(0.37)^2}{2}+(0.17)^2} \text{ or } 0.31 \text{ per cent.}$$

Corresponding figures for Calama are:

$$\sqrt{\frac{(0.20)^2}{2}+(0.12)^2} \text{ or } 0.19 \text{ per cent.}$$

SECONDARY WATER-VAPOR CORRECTION.

As stated in Volume III of these Annals, page 43, we became convinced by statistical methods that our solar-constant values on Mount Wilson were not wholly freed from atmospheric influence. In short, when the solar-constant values for each year were divided into groups selected between certain limits of precipitable water prevailing in the atmosphere, it appeared that the mean solar-constant value for the successive groups diminished with increase in the atmospheric humidity. Each year of observation at Mount Wilson has been discussed separately from this point of view by Mr. Fowle. Singularly enough, it seems to be shown that for all the years alike a linear correction of approximately 0.1 per cent increase of the solar-constant value for each millimeter of precipitable water in the vertical atmospheric column is proper. This correction has accordingly been applied to all Mount Wilson values and the originally computed values called E_0 become thereby the final values called E'_0 in the tables.

We have made the same sort of a statistical investigation of the solar-constant values obtained at Calama by the long method.[1] In order that the investigation should be both more direct and easier we used the logarithm of ρ/ρ_{sc} at air mass 3 as the function of prevailing humidity instead of precipitable water. Long-method solar-constant values taken at Calama from July, 1918, to July, 1919, were employed as follows:

Mean of log ρ/ρ_{s0}	$\bar{1}.510$	$\bar{1}.573$	$\bar{1}.631$	$\bar{1}.673$	$\bar{1}.726$	$\bar{1}.774$	$\bar{1}.828$	$\bar{1}.867$
Number of observations	22	20	32	35	37	34	38	26
Mean solar constant	1.9392	1.9447	1.9426	1.9485	1.9362	1.9373	1.9516	1.9550

The whole range of mean solar-constant values for this great range of humidity is but 0.0188 calories. Except for the two final groups there could be no suspicion whatever of a tendency toward correlation between the humidity and solar-constant values.

The less numerous long-method Calama values of July 1, 1919, to July 26, 1920, similarly treated yield results as follows:

Mean of log ρ/ρ_{s0}	$\bar{1}.497$	$\bar{1}.663$	$\bar{1}.749$	$\bar{1}.830$
Number of observations	17	19	20	14
Mean solar constant	1.9506	1.9504	1.9474	1.9525

[1] A different treatment amounting to the same thing was made with the short-method values at Calama as will be described below.

There is here even less indication of correlation between humidity and solar-constant value.

We have not thought ourselves warranted in assuming any connection between them on the basis of this evidence, feeling that it is probable that all the range in solar-constant values may very probably be from solar and accidental causes.

If we inquire why it is that the Mount Wilson values require correction for humidity and yet the Calama values, where the variation of humidity is fully as great, require none, we may remark that the purity and detail of the spectrum as observed at Calama is very much higher than that observed at Mount Wilson. A great number of Fraunhofer lines appear as deep indentations of the energy curves at Calama which are not to be seen on Mount Wilson curves. This difference materially influences the drawing of the smooth curves to which the measurements are made, and especially affects the curves in the upper infra-red region between A and ρ. The water vapor bands, where the smooth curve must be interpolated for long distances, are thus altered as between the observations at the two stations.

That this difference in definition, due in part to the use of greater sensitiveness of the galvanometer employed in Calama, has this tendency, receives some confirmation from the fact that when in 1919 the definition of the spectrum at Mount Wilson was abominably bad, owing to defective stellite mirrors, an additional additive correction of 2.2 per cent was required to bring the Mount Wilson values up to the Calama scale, and to the Mount Wilson scale of the preceding and following years.

THE SHORT METHOD.

As more fully described elsewhere, the short method depends on the fact that the greater the atmospheric humidity and the brightness of the sky, the smaller is the atmospheric transmission. Measurements are made with the pyranometer of the brightness of the sky within a zone extending about 15° on every side from the sun. Bolographs made simultaneously give the quantity which measures the ratio of the intensity at the bottom of the band ρ to the intensity indicated by the smooth curve over this band. This ratio is an index of the atmospheric humidity prevailing between the observer and the sun. By dividing the pyranometer reading, P, by ρ/ρ_{sc}, there is obtained a function which we call $F=P\frac{\rho_{sc}}{\rho}$

Plots were prepared at Calama corresponding to air masses 3, 2, and 1.5 for each of the 36 wave lengths at which measurements of the smooth curve were made there, connecting atmospheric transmission coefficients, a, with functions F. These plots were based on the results of long method observations on about 60 excellent days. Numerous secondary plots were also prepared connecting functions, F, with air masses under all usual circumstances of haziness and humidity, so that if observations were made at air masses other than 3, 2, and 1.5, the functions, F, observed could be reduced to the values they would have had if made under the prevailing atmospheric circumstances at one of these chosen air masses. With such reduced values the function-transmission plots were entered, and thereby the atmospheric transmission coefficients for all the smooth curve places were read off. By the aid of these the ordinates of the bolograph were reduced to the values proper to zero air mass. In this reduction, if b is the ordinate observed for a certain place at air mass m, a, the corresponding transmission coefficient, and b_0, the ordinate at zero air mass:

$$b=b_0a^m$$

Whence in the ordinary usage of computations

$$b_0=\text{antilog}[\log b+m \text{ colog } a]$$

Adopting, as far as convenient, the symbols used in Volume II of these Annals, page 79, the solar constant is

$$S=\left(\frac{r}{r_0}\right)^2\cdot\frac{R}{\Sigma bc}\cdot\Sigma b_0c$$

where r and r_0 are the actual and mean solar distances, R the mean pyrheliometer reading and c the multiplier to correct the observed ordinate of the bolograph for the relative losses experienced in the optical train.

We wish now to determine the probable error of such a determination for one day relative to another—that is, not considering absolute pyrheliometry. It is not needful to consider the accuracy of the values c, since now that stellite mirrors are used these occur unchanged day after day in approximately the same relation to other quantities, and moreover in both numerator and denominator of the expression for the solar constant. Neither is it necessary to consider errors of the quantity Σbc, except so far as to note the influence of erroneous determinations of the combined area of the infra-red water-vapor bands. For in all other respects the several bolometric ordinates, b, of the smooth curve are but in the nature of weights applied to the several terms in the expression $\Sigma cb\left(\frac{1}{a^m}\right)$. Small differences of the order of 1 per cent in these weights would but inappreciably affect the result on the solar constant.

We must fix attention then merely on the probable error of the individual values a^m, the accumulation of these errors in the summation $\Sigma cb\left(\frac{1}{a^m}\right)$, the probable error of R, and the probable error of Σcb, due to erroneous determinations of the band areas.

The probable error of a depends on the probable error of the function-transmission plots and on the probable error of the function itself. The reader may consult figures 6 and 7 in which are shown the Calama plots for air masses 3 and 2 as derived from data of many days. He will then perceive that for all of the most important region of spectrum which is covered by the plots marked 30, 28, 26 . . . 10, 9, 8, a change of tenfold in F produces no more than 7 per cent in a at the most unfavorable case, while for the most important part of these curves a change of tenfold in F produces less than 3 per cent in a. Since it is easy to observe ρ/ρ_{sc} to 2 per cent accuracy, and P to 2 per cent accuracy, the probable error of F is less than 3 per cent. Hence the probable error of a due to inaccuracy in F is a negligible quantity compared to other errors about to be discussed.

The principal source of error in the short method is the uncertainty of the representation of the atmospheric transmission coefficients by the function-transmission plots for the numerous wave lengths. These are purely empirical, based on atmospheric transmission coefficients determined by the long method of high and low sun observations on homogeneous rays. Such high and low sun determinations are every day liable to error from progressive clearing or obscuring of the atmospheric transparency. Hence a large number of values of a by the long method is required to form a basis for the short method at any observing station. Unfortunately these values will be unfavorably distributed. A great proportion of them will correspond to the small and medium values of the function F, for at such times there is less apt to be formation of cirrus or cumulus clouds, or streaks of haziness such as produce poor long-method observations, or even cut them off altogether. On the other hand the function-transmission curves need to be at their best for large function values, because in these atmospheric conditions not only are the values of a smaller and the extrapolation greater but short-method determinations alone are apt to be practicable, by utilizing openings between clouds, when long-method values are not to be thought of.

If observations should go on indefinitely over a long term of years at a given station, it would be possible doubtless to continually improve the function-transmission curves by employing more and more long-method observations, until the source of error involved in improper location of the curves would be eliminated to a high degree. Hitherto this has not been possible. By examination of the curves for Calama, shown in figures 6 and 7, which were founded on about 60 high grade long-method determinations the reader will see for instance in curve 22 at wave length 0.62 micron, of the plot for air mass 2, at mean a approximately 0.90, the following distribution of points:

Function	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9
Number values	14	13	16	4	4	4	1	2
Per cent mean deviation from curve	0.57	0.78	0.47	0.37	0.95	0.93	0.50	0.25

We find it difficult or impossible to deduce trustworthy values of the probable error of the various regions of this and others of the curve from such data, but we must admit that while for all of the important curves Nos. 0 to 40, the region of function values 1–4 is so well determined that we should doubt if the error of the curve position exceeds 0.2 per cent in this interval, the parts of the curves for function values 4–9 are so meagerly determined that errors even of 1 per cent are not improbable for the highest values of the function. In extrapolating from $m=1.5$, $m=2.0$, and $m=3.0$ by the formula $b_0=\text{antilog}\ [\log\ b+m\ \text{colog}\ a]$ changes in a of certain percentage magnitudes produce respectively 1.5, 2, and 3 times as great effects in percentage change of b_0.

The individual errors in the various values of cb_0 should be to a certain extent minimized in the summation of 34 such terms used in determining the area of the energy curve outside the atmosphere, because some errors will probably be of opposite sign from others. But it is not probable that this tendency operates to justify using the square root of the number of terms as used in least squares, because the same changes of transparency in the long-method observations which scatter the determining points for one of the function-transparency curves will probably operate in the same sense for many or all of the curves. That is, on a day of long-method observation where the transparency steadily increases, nearly all of the values of a determined by the long method will probably be too high, and vice versa.

Thus we may suppose that short-method determinations from 1.5, 2, and 3 air masses will be respectively approximately as erroneous in percentage from the true values as the function-transmission curves are on the average erroneous at the values of function employed. As regards the Calama curves, then, we should not expect from this cause errors as great as 0.5 per cent in determinations where the functions were those proper to dry, clear days. But for the most humid, hazy days errors up to 2 or 3 per cent could occur.

The third cause in the production of error by the short method lies in the pyrheliometry. As we have seen, the probable error of a single pyrheliometer measurement at Calama is to be fixed at 0.20 per cent. Every short method day of observation at Calama represents from six to twelve such pyrheliometer measurements. Hence the probable error of R in our formula is from 0.08 to 0.06 per cent, quantities of very satisfactorily small order, and indeed negligible compared to other errors.

The fourth cause of error is the improper estimation of the total area of the water-vapor bands of the infra-red to be subtracted from the smooth curve area of the bolograph. This probable error we have hitherto given as 1.5 per cent. The area of the bands at Calama ranged from 6 to 15 per cent of the area remaining after their removal, so that this source of probable error is to be fixed at from 0.09

to 0.22 per cent for a single short-method determination, or from 0.05 to 0.13 per cent for a mean result of a day when three determinations occurred. We see therefore that all other sources of error in the short method at Calama are dwarfed beside the one which comes from insufficient determination of the function-transmission curves. Fortunately an improvement of the final results is possible by statistical methods as follows:

Firstly, from such knowledge as we have obtained of the variation of the sun in short periods, gained by many years of long-method observations, we may safely assume that the mean of 20 or 30 days of solar-constant values selected at random over several months of a single year will be nearly constant.

Secondly, since the short method is based on the longer and fundamental one, the mean of a fair number of days' results by the long method should agree closely with the mean of the results of the same days by the short method.

To apply the first of these two criteria we have separated the short-method Calama values into divisions according to air mass of the curves used in determining them, that is, 1.5, 2, 3, respectively. In each division we have separated the results into groups according to function value prevailing. In each of the groups used there were 20 or more solar-constant values, of which we took the means for each group. These results are as follows:

TABLE 46.—*Statistical test of the short method.*

AIR MASS 1.5.

Function	1–2	2–3	3–4	4–5	5–6	6–9	>9
Mean solar constant	1.950	1.949	1.956	1.958	1.962	1.959	1.954
Mean function	169	249	345	443	530	751	1,041
Number of values	20	43	36	16	22	39	12

AIR MASS 2.

Function	1–2	2–3	3–4	4–5	5–6	6–7	7–9	>9
Mean solar constant	1.945	1.943	1.945	1.957	1.963	1.963	1.979	1.983
Mean function	174	243	340	450	544	665	780	1,151
Number of values	66	95	41	27	13	7	14	24

AIR MASS 3.

Function	2–3	3–4	4–5	5–6	6–7	7–9	9–13	>13
Mean solar constant	1.940	1.939	1.940	1.933	1.938	1.951	1.974	1.985
Mean function	250	344	452	544	632	775	1,094	1,709
Number of values	64	61	23	11	12	13	6	12

These data are shown graphically in figure 9. Apparently the parts of the function-transparency curves associated with large function values indicate too small values of *a*, so that the solar constant values run too high in this region.

The result is confirmed by the comparison (Table 47) between solar-constant values by the long and short methods observed at Calama in the months December to March, 1919–20, when, as the low values of ρ/ρ_{sc} indicate, the atmospheric humidity was very great, and the functions very large. In contrast to these data we give corresponding values for a number of dates when, as indicated by values of ρ/ρ_{sc}, the humidity of the atmosphere was small and the functions occurred in a well-determined portion of the function-transmission curves.

The assembled data of the preceding tables left no reasonable doubt in our minds of the propriety of correcting the short-method values obtained at Calama.

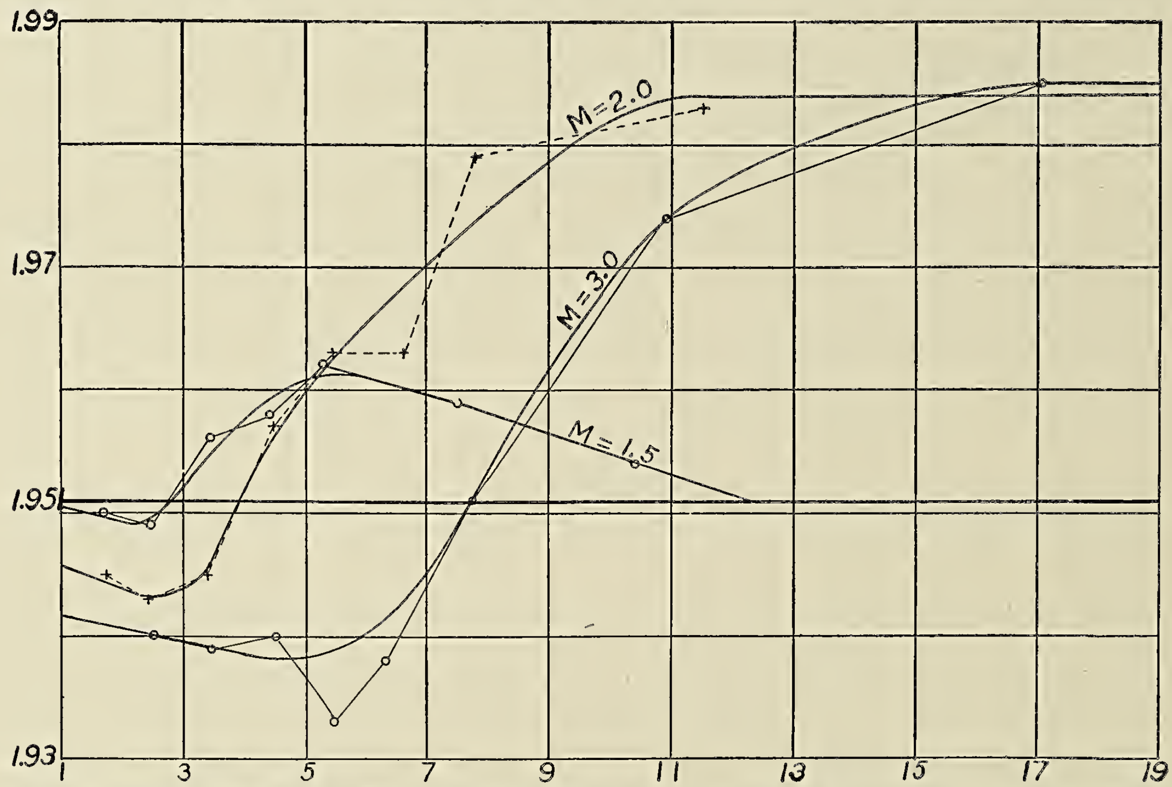


FIG. 9.—Statistical test of the short method. Ordinates: Solar-constant values. Abscissae: "Function" values. Corrections are derived from departures of smooth curves from line 1.951.

We had already assembled all the long-method observations made at Calama in the interval July, 1919, to July, 1920, inclusive, and had arranged them in groups according to values of log ρ/ρ_{sc} prevailing. No influence of humidity appeared in the solar-constant values. So we regarded the general mean, 1.951, of these long-method values as the value to which the short-method groups should all be referred. It might be urged against this assumption that if a certain period of low transparency had for instance high solar-constant values, such a reference to a standard value was unjust. But the division of the long-method values into groups depending on the prevailing humidity which runs along with the transparency, had overcome this objection. Hence we felt justified in making the value 1.951 the basis for our corrections of the short-method values.

TABLE 47.—*Comparison of long and short method solar-constant values determined at Calama, Chile, 1919–20.*

Date.	ρ/ρ_{90}	E_0	m_3	m_2	$m_{1.5}$	m_3-E_0	m_2-E_0	$m_{1.5}-E_0$
1919.								
Dec. 5......	0.472	1.958	1.959	1.959	1.944	0.001	0.001	−0.014
12......	.415	1.926	1.972	1.969	1.953	.046	.043	.027
22......	.364	1.959	1.988	1.977	1.963	.029	.022	.004
23......	.330	1.967	1.986	1.970	1.954	.019	.003	−.013
24......	.363	1.932	1.997	1.975	1.976	.065	.043	.044
31......	.304	1.964	2.002	1.975	1.979	.038	.011	.015
1920.								
Jan. 2......	.454	1.971	1.974	1.973	1.959	.003	.002	−.012
19......	.251	1.956	2.053	2.011	1.976	.097	.055	.020
25......	.275	1.957	2.008	1.979	1.969	.051	.022	.012
Feb. 10......	.276	2.009	2.012	1.985	1.978	.003	−.024	−.031
25......	.265	1.973	1.993	1.994	1.983	.020	.021	.010
Mar. 11......	.331	1.961	1.985	1.976	1.981	.024	.015	.020
14......	.344	1.932	1.985	1.968	1.956	.053	.036	.024
17......	.307	1.931	1.972	1.964	1.964	.041	.033	.033
27......	.492	1.967	1.978	1.964	1.956	.011	−.003	−.011
29......	.426	1.953	1.976	1.975	1.966	.023	.022	.013
30......	.451	1.924	1.955	1.952	1.940	.031	.028	.016
31......	.425	1.959	1.965	1.937	1.957	.006	−.022	−.002
Mean values.	.364	1.955	1.987	1.972	1.964	+.031	+.017	+.010
1919.								
Nov. 5......	0.634	1.956	1.971	1.977	1.966	0.015	0.021	0.010
10......	.560	1.950	1.968	1.950	1.961	.018	.000	.011
1920.								
Apr. 14......	.566	1.954	1.961	1.958	1.952	.007	.004	−.002
May 3......	.600	1.983	1.955	1.962	1.950	−.028	−.021	−.033
11......	.688	1.969	1.972	1.970	1.961	.003	.001	−.008
20......	.633	1.966	1.966	1.947	....	.000	−.019	....
30......	.747	2.008	1.995	1.967	....	−.013	−.041	....
June 2......	.758	1.931	1.949	1.938	....	.018	.007	....
24......	.680	1.932	1.959	1.925	....	.027	−.007	....
Mean values.	.654	1.961	1.966	1.955	1.958	+.005	−.006	−.004

The corrections indicated by the curves of figure 9 were accordingly applied to the originally obtained separate short-method values which have been published from month to month in the Monthly Weather Review of the United States Weather Bureau. From the corrected values, weighted mean values were obtained for the individual days. We gave long-method values of grade "e−" or better, weight 2, other long-method values, weight 1; short-method values from air masses 1.5 and 2; weight 2; and those from air mass 3, weight 1. These weighted mean values are given in the final column of Tables 43 and 44.

This system of weights was adopted from consideration that though the long method is the fundamental one, its results are apt to be affected by progressive alterations of atmospheric transparency, so that only the very best long-method values are deserving of equal weight to the best short-method values which are not affected by alterations of atmospheric transparency. Short-method values from air mass 3 are obviously of less weight because of longer extrapolation and doubtfulness of sky condition around the sun so close to the horizon.

CHAPTER VI.

APPLICATIONS OF SOLAR RADIATION MEASUREMENTS.

I. EVIDENCES OF THE VARIABILITY OF THE SUN.

At the time when Volume III of these Annals was prepared, the evidences of the variability of the sun depended mainly on the work done simultaneously at Mount Wilson, California, and Bassour, Algeria, in the years 1911 and 1912. In the years which have elapsed since then several confirmatory evidences have been discovered.

1. SIMULTANEOUS SOLAR-CONSTANT OBSERVATIONS AT REMOTE STATIONS.

The reader will find the individual solar-constant measurements made at different stations in the tables of the preceding chapter, and it is only necessary here to institute a proper comparison between them. The observations at Hump Mountain, North Carolina, are too inaccurate for useful comparison. We will compare the results obtained at Mount Wilson, California, and Calama, Chile, in the years 1918, 1919, and 1920.

For the purposes of the comparison, it is necessary to have the observations strictly on a common scale. No change was needed for the year 1918. In 1919, a systematic error affected all the Mount Wilson values to make them smaller than the Calama value of 1919, and the Mount Wilson values of 1918 and 1920. This we think was due to bad definition and stray light from defective stellite mirrors used in the spectroscope during that year. In order to eliminate this systematic error, all of the Mount Wilson values of 1919 were increased by 2.20 per cent. A similar adjustment seemed desirable for 1920, but much smaller. All Mount Wilson values for 1920 were increased by 0.36 per cent.

Sixteen values were omitted—six of 1918, six of 1919, four of 1920. These included *all* which were graded "p" at one or both stations, whether closely agreeing or not, and one or two others for which notes made of the conditions of the sky showed an obvious explanation of wide divergences. There remained 106 observations for comparison. These values are given in Tables 48, 49, and 50.

TABLE 48.—*Comparison of Calama and Mount Wilson solar-constant values, 1918.*

Date.	Calama.	Mount Wilson.	Δ
1918.			
July 27	1.944	1.949 e.—	−0.005
28	1.901	1.947 e.—	− .046
29	1.899	1.908 g.	− .009
Aug. 3	1.966	1.946 g.	+ .020
5	1.954	1.953 v.g.—	+ .001
8	1.955	1.936 g.—	+ .019
10	1.954	1.962 g.	− .008
11	1.965	1.956 v.g.	+ .009
12	1.959	2.008 p.	....
14	1.925	1.948 p.	....
19	1.948	1.942 g.+	+ .006
20	1.940	1.938 e.	+ .002
21	1.995	1.971 v.g.—	+ .024
22	1.953	1.949 e.+	+ .004
23	1.979	1.957 e.	+ .022
29	1.954	1.929 e.+	+ .025
Sept. 1	1.980	1.979 v.g.	+ .001
6	1.937	1.956 v.g.—	− .019
9	1.931	1.871 p.	....
16	1.960	1.997 v.g	− .037
19	1.943	1.991 p.	....
26	1.950	1.963 v.g.—	− .013
Oct. 2	1.932	1.901 p.	....
9	1.941	1.950 v.g.	− .009
10	1.950	1.942 e.	+ .008
11	1.865	1.981 g.	....

NOTE.—Sept. 19 at Mount Wilson and Oct. 11 at Calama rejected for apparent variability of the sky during the observations.

TABLE 49.—*Comparison of Calama and Mount Wilson solar-constant values, 1919.*

Date.	Calama.	Mount Wilson original.	Mount Wilson corrected.	Δ
1919.				
June 15	1.903	1.848 p.	....	....
16	1.927	1.911 g.	1.953	−0.026
21	2.013	1.956 e.—	1.999	+ .013
22	1.959	1.917 g.+	1.959	.000
23	1.975	1.892 g+.	1.934	+ .041
24	1.952	1.902 v.g.	1.944	+ .008
25	1.955	1.902 e.	1.944	+ .011
26	1.926	1.888 g.	1.929	− .003
27	1.938	1.895 v.g.	1.937	+ .001
28	1.972	1.926 v.g.?	1.969	+ .003
29	1.969	1.932 g.	1.974	− .005
30	1.962	1.921 g.—	1.963	− .001
July 1	1.942	1.919 e.—	1.961	− .019
2	1.925	1.871 g.+	1.912	+ .013

TABLE 49.—*Comparison of Calama and Mount Wilson solar-constant values, 1919*—Continued.

Date.	Calama.	Mount Wilson original.	Mount Wilson corrected.	Δ
1919.				
July 3	1.928	1.926 g.	1.969	− .041
6	1.971	1.909 g.+	1.951	+ .020
9	1.954	1.950 g.	1.993	− .039
10	1.958	1.904 v. g.	1.946	+ .012
11	1.954	1.903 g.	1.945	+ .009
14	1.960	1.922 g.	1.964	− .004
20	1.961	1.804 v. p.	....	....
21	1.957	1.953 g.−	1.996	− .039
22	1.971	1.901 e.	1.943	+ .028
23	1.967	1.910 v. g.+	1.952	+ .015
24	1.955	1.903 g.	1.945	+ .010
27	1.925	1.941 p.	....	....
29	1.959	1.942 v. g.	1.985	− .026
30	1.936	1.907 v. g.+	1.949	− .013
31	1.930	1.884 v. g.−	1.925	+ .005
Aug. 1	1.959	1.919 v. g.−	1.961	− .002
2	1.943	1.892 v. g.−	1.934	+ .009
3	1.980	1.916 v. g.−	1.958	− .022
4	1.959	1.908 g.+	1.950	+ .009
5	1.963	1.920 g.	1.962	+ .001
7	1.962	1.855 p.	....	....
10	1.960	1.916 e.	1.958	+ .002
13	1.924	1.880 p.+	1.921	+ .003
14	1.946	1.904 v. g.+	1.946	.000
19	1.927	1.883 v. g.−	1.924	+ .003
22	1.966	1.885 g.	1.927	+ .039
23	1.961	1.944 p.	....	....
28	1.957	1.922 p.	....	....
29	1.965	1.919 v. g.−	1.961	+ .004
30	1.951	1.910 g.	1.952	− .001
Sept. 1	1.937	1.909 g.	1.951	− .014
2	1.918	1.880 v. g.	1.921	− .003
3	1.934	1.909 v. g.	1.951	− .017
4	1.946	1.895 v. g.	1.937	+ .009
5	1.938	1.891 e.	1.933	− .005
6	1.946	1.894 e.	1.936	+ .010
7	1.941	1.892 g.	1.934	+ .007
8	1.956	1.900 g.	1.942	+ .014
11	1.948	1.932 v. g.	1.975	− .027
12	1.917	1.899 e.	1.941	− .014
13	1.956	1.915 v. g.+	1.957	− .001
17	1.932	1.894 e.	1.936	− .004
18	1.948	1.845 p.	....	....
19	1.957	1.923 g.−	1.965	− .008
20	1.957	1.917 e.	1.959	− .002
21	1.957	1.918 g.	1.960	− .003

TABLE 50.—*Comparison of Calama and Mount Wilson solar-constant values, 1920.*

Date.	Calama.	Mount Wilson original.	Mount Wilson corrected.	Δ
1920.				
July 8	1.951	1.926 e.	1.933	+0.018
9	1.944	1.942 v.g.	1.949	− .005
10	1.932	1.937 e.−	1.944	− .012
11	1.945	1.932 v.g.−	1.939	+ .006
12	1.944	1.949 v.g.−	1.956	− .012
18	1.933	1.919 v.g.−	1.926	+ .007
19	1.932	1.927 v.g.	1.934	− .002
20	1.950	1.931 v.g.+	1.938	+ .012
21	1.965	1.856 p.	....	....
24	1.950	1.932 v.g.−	1.939	+ .011
25	1.943	1.918 v.g.+	1.925	+ .018
26	1.950	1.958 v.g.−	1.965	− .015
Aug. 3	1.919	2.090 p.	....	....
4	1.922	1.926 v.g.−	1.933	− .011
5	1.927	1.921 v.g.	1.928	− .001
7	1.932	1.945 e.+	1.952	− .020
8	1.922	1.912 g.	1.919	+ .003
9	1.937	1.924 v.g.	1.931	+ .006
12	1.932	1.951 v.g.+	1.958	− .026
13	1.979	1.968 v.g.	1.975	+ .004
14	1.921	1.922 v.g.	1.929	− .008
15	1.920	1.903 v.g.−	1.910	+ .010
17	1.968	2.016 e.	2.023	− .055
18	1.942	1.937 e.	1.944	− .002
19	1.940	1.922 v.g.	1.929	+ .011
20	1.924	1.976 e.−	1.983	− .059
21	1.940	1.935 e.	1.942	− .002
22	1.945	1.990 g.	1.997	− .052
23	1.942	1.866 p.	....	....
27	1.928	1.912 g.+	1.919	+ .009
29	1.915	1.915 e.	1.922	− .007
30	1.921	1.994 e.−	2.001	− .080
Sept. 2	1.956	1.912 g.+	1.919	+ .037
3	1.952	1.917 e.	1.924	+ .028
5	1.936	1.920 v.g.	1.927	+ .009
6	1.901	1.891 v.g.	1.898	+ .003

We shall set forth the results of the comparison of these values in three ways. First by the method of the correlation coefficient. Proceeding in the usual manner,[1] we find as the coefficient of correlation between the 106 solar-constant values for 1918, 1919, and 1920 observed at Mount Wilson and Calama on the same days and given in Tables 48, 49, 50, $r = +0.491 \pm 0.050$.

Readers familiar with the method of correlation will recognize the high degree of certainty thus indicated that a common cause operates to modify simultaneously

[1] See, for instance, Smith, "Agricultural Meteorology," pp. 54–57.

in the same sense the observations at the two stations. Some readers may think it reasonable to suppose that that cause is terrestrial. But they should reflect that the two stations are 5,000 miles apart, on opposite sides of the Equator, and at different altitudes. To us it appears easier to suppose the cause extra-terrestrial and either in the sun or in the path of the rays between the sun and the earth.

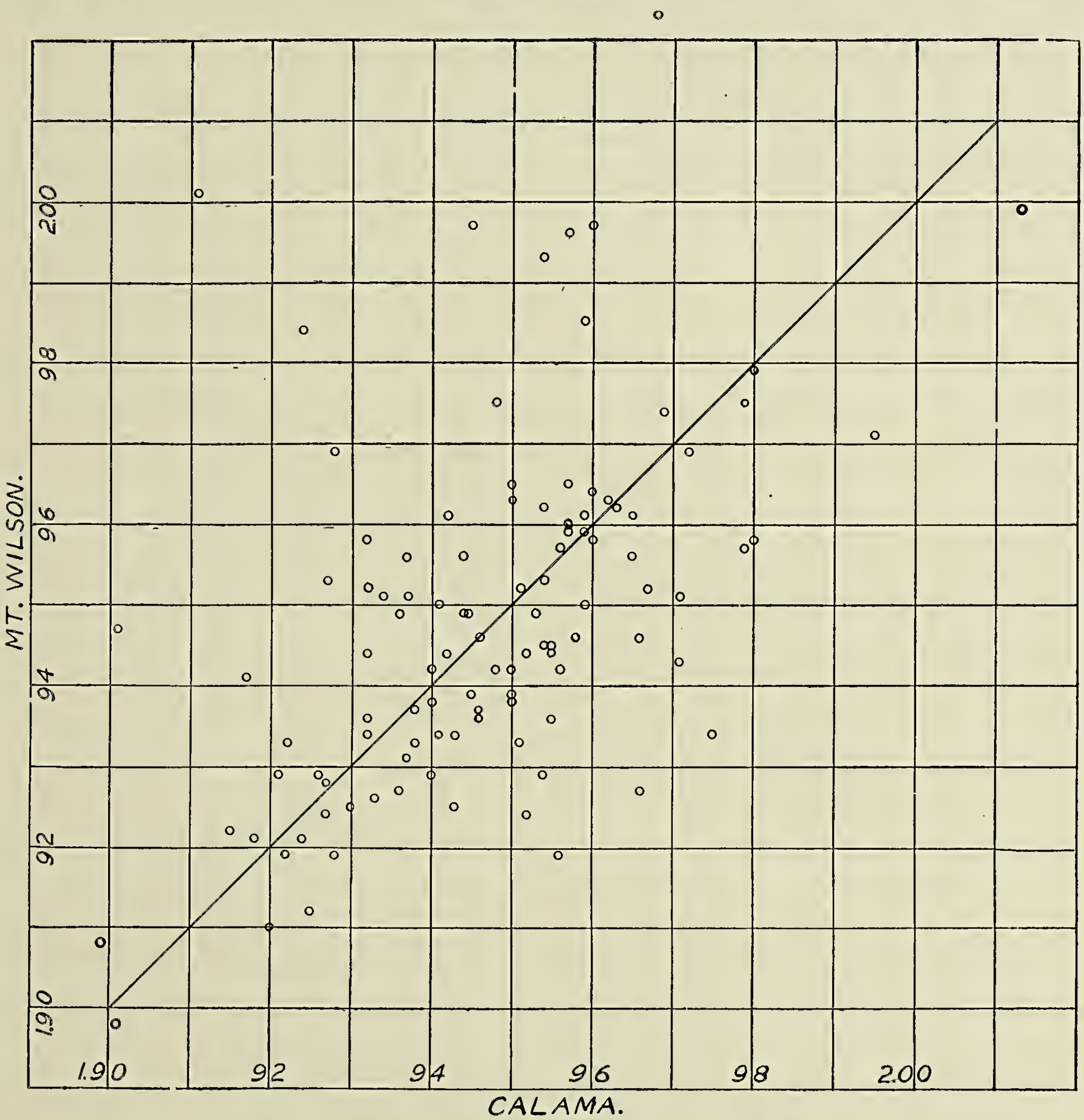


FIG. 10.—Comparison of Mount Wilson and Calama solar-constant values.

Secondly, a graphical comparison may be made conveniently as was done in figure 15, page 128, Volume III of these Annals, showing the correlations between solar constant values at Mount Wilson and at Bassour. A similar figure (fig. 10) is now given for the correlation between results at Mount Wilson and at Calama. Each point of the plot represents the values obtained on one day when the solar constant was determined at both stations. Ordinates represent Mount Wilson values, abscissæ the corresponding Calama values. If the sun had varied, but the observations were without error, the points would obviously all be found on a line at 45° inclination. Accidental errors prevent coincidence with such a line, but the points are found so distributed that it is obviously the best representation of them. The average deviation of Mount Wilson from Calama is only 0.6 per cent, and may be reasonably ascribed to accidental error of measurement and error due to changes of sky transparency. The probable error of a single day's observation at one station is only 0.4 per cent. High values at one station are high at the other, and vice versa. A total range of solar variation of 5.4 per cent is indicated by the two extreme points, and many points are found which indicate a range as great as 2.5 per cent.

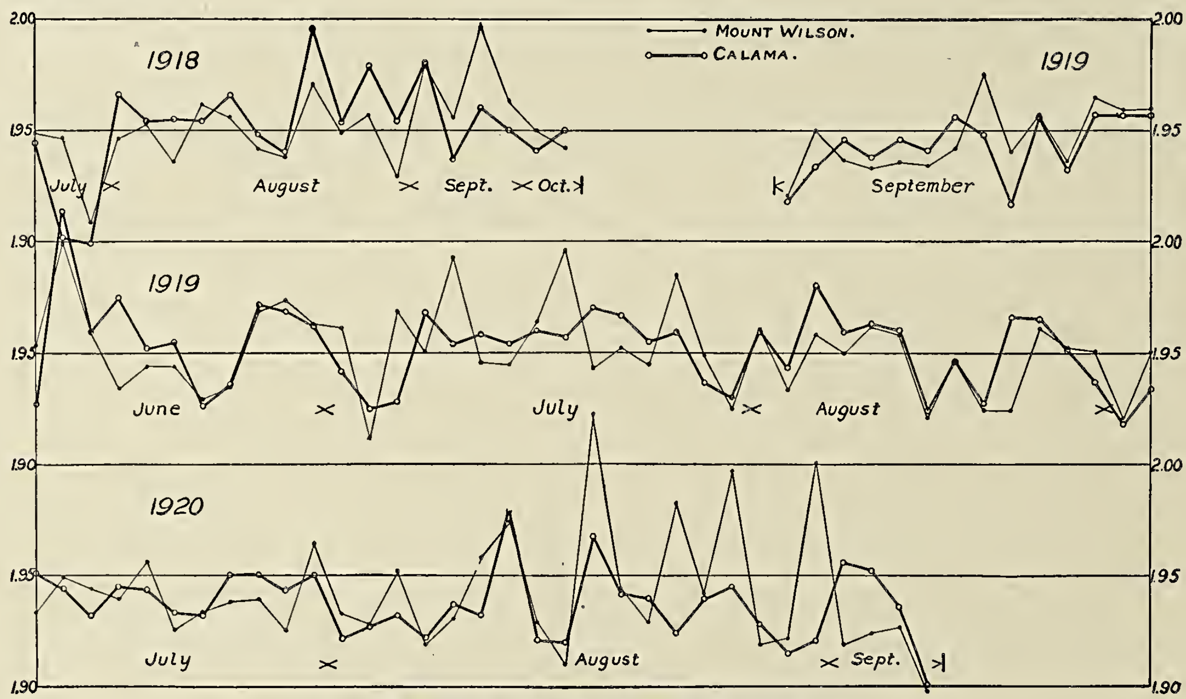


FIG. 11.—March of Mount Wilson and Calama solar-constant values.

Thirdly, we give the values again in figure 11 showing that generally they march together from day to day. To avoid annoyance from breaks in the curves, we have closed up the ranks in abscissæ by altogether omitting days when satisfactory observations at both stations are lacking. We desire to draw attention particularly to the year 1919, which exhibits considerable changes both of short and long ranges. See also the generally lower values prevailing in 1920.

It is but fair to remark that a part of the discrepancies observable between the two curves must, if the sun is variable, be due to the three hours difference in time between the observing periods at the two stations incident to their difference in longitude. Secondly, if the sun's radiation is rapidly increasing while a determination of the solar constant by the long method is in progress, the result must be too high, and vice versa. This also must produce discrepancies.

2. VARIATIONS OF DISTRIBUTION OF RADIATION ALONG THE DIAMETER OF THE SOLAR DISK.

In a later chapter we give the results of investigation of the distribution of radiation along the east and west diameter of the solar image. These investigations, begun in Washington and carried on there to the year 1907, were taken up again at Mount Wilson in 1913, and made on practically every occasion when the solar constant was observed up to 1920, inclusive. Readers should consult figures 28 to 34 which show graphically the results obtained.

As appears in Chapter VII, the sun is always brighter at the center of the disk than near the limb. This contrast of brightness is greater for short wave lengths than for long. The contrast varies slightly from year to year in each wave length. Slight variations also occur from day to day. While the association between variations of contrast and variations of solar constant is complex, yet the following characteristics seem to be fairly indicated.

A. With the exception of the year 1915, higher average solar contrast accompanies higher average solar constants, in years when, as indicated by the visible solar phenomena, the general solar activity is greater.

B. In the years 1913 and 1918, and to a less degree in the years 1914 and 1915, lower solar contrast generally accompanies higher solar constants in the day-to-day fluctuations.

C. In other years, notably in 1916, and to a less extent in 1917, higher solar contrast generally accompanies higher solar constants in the day-to-day fluctuations.

D. At times in all years, and in some years almost throughout, no long periods of definite correlation, either positive or negative, between solar contrast and solar constant seem to occur.

These apparently hopelessly conflicting facts are reconcilable by a threefold hypothesis of solar variation which seems to be quite reasonable in view of probable solar conditions. It is as follows:

Cause A: Variation in solar activity varies the rate of upheaval of fresh radiating surfaces and so alters the sun's effective temperature.

Effect A: Increased solar radiation attends increased solar contrast. For if the solar radiation were zero the solar contrast would be zero also.

Cause B: Variation occurs in the transparency of the outer solar envelopes.

Effect B: Increased solar radiation attends decreased contrast. For if the transparency increases, its increase produces most effect at the solar limb where the depth of the layer in question is increased by obliquity of the line of sight.

Cause C: Solar rotation brings into the beam columns of more or less transmissibility.

Effect C: Increased solar radiation attends increased pseudocontrast. For if the column of increased transparency points roughly toward the earth at a given time, it is most apt to arise from (roughly speaking) the center of the solar disk. Hence this central part of the disk appears brighter relative to the limbs.

If these suggestions are admitted, it is obvious that combinations of A or C with B may produce conflicting results according to which of the causes is in predominance.

Notwithstanding this conflict of evidence, the solar-contrast work supports the variability of the sun. For so high a degree of positive or of negative correlation as continues during several long intervals, notably in 1913 and 1916, could hardly occur once in a thousand times fortuitously in accordance with the theory of probability. For example, we have determined the coefficient of correlation between solar-constant and solar-contrast numbers for the period August 10 to September 18, 1916, when almost daily observations were secured of both variables. We find:

$$r = -0.363 \pm 0.097.$$

That is to say, decreasing solar-contrast numbers (increasing contrast) is in correlation with increasing solar-constant values with a coefficient about four times its probable error.

Similar computations for 1913, as published already, gave:

$$r = +0.601 \pm 0.067.$$

In this case the correlation in the opposite sense is even more strongly indicated.

Thus we find, from the solar-contrast investigation, purely solar phenomena which vary in apparently close connection with the variations which are revealed by the solar-constant work. This circumstance may therefore be regarded as an independent confirmation of solar variation.

3. CORRELATION BETWEEN SOLAR VARIATIONS AND TERRESTRIAL WEATHER.

Several investigators, Arctowski, Helland-Hansen and Nansen, and notably Clayton, have made investigations of the dependence of the temperature and barometric pressure, at different stations upon the earth's surface, on the intensity of the solar radiation as measured by the solar-constant observations at Mount Wilson and at Calama. These investigators all agree that there is a well-indicated dependence of the temperature, pressure, and probably also of the rainfall, upon the variations of the sun. Unfortunately for the purposes of forecasting, the dependance appears to be very complicated, so that while increase in solar radiation causes increase in the temperature of some terrestrial stations, it produces at the same time decrease in the temperature of others. Not only is this encountered, but also a still more troublesome feature, namely, that the effect on the temperature is at some times of the year in one sense and at other times the opposite at a single terrestrial station. Thus at Buenos Aires, according to Clayton's investigation, in the months October to February, following increased solar-constant values increased temperatures prevail for several days, while the opposite is true for the remaining months. Temperature effects persist, however, for several weeks after large solar changes, and the cycle of effects is quite complicated, as is shown by the accompanying figure 12.

The three curves each represent four years of observation. They show the average march of temperature departures at Buenos Aires, as published by H. H. Clayton, for nineteen days next following days of maximum, mean, and minimum solar radiation. The curves show mean results for the years 1913, 1914, 1915, and 1918 for the months May to November.

The solar observations were made by the Smithsonian Astrophysical Observatory, at Mount Wilson, California, more than six thousand miles from Buenos Aires. Mount Wilson is separated from Buenos Aires by 60° in longitude and 70° in latitude. There can be no local terrestrial connection, so that the results evidently indicate that variations in the sun produce large variations of temperature on the earth.

The curves marked "Max.," "Mean," and "Min." correspond, respectively, to mean values of the "solar constant" of 2.00, 1.95, and 1.90 calories per square centimeter per minute.

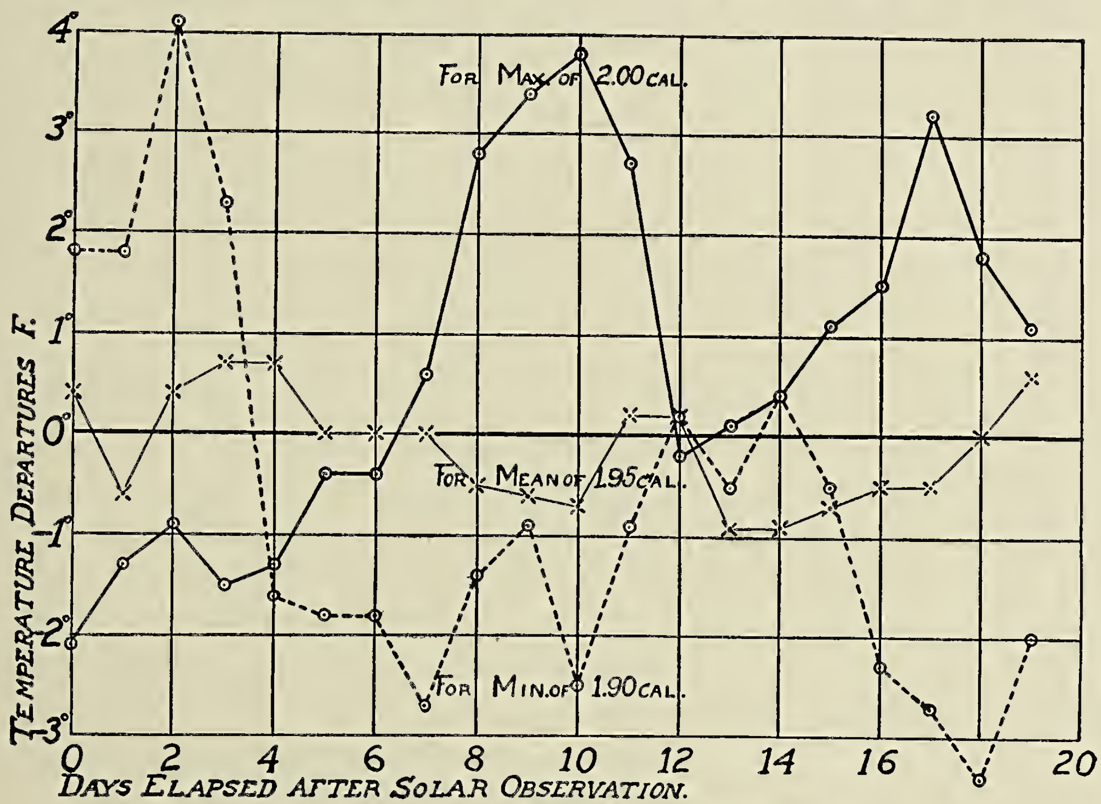


FIG. 12.—The solar constant and Buenos Aires temperature (Clayton).

While the temperatures following minimum "solar-constant" values are generally lower than the normal from the third to the nineteenth day, they are above the normal before the third day; while those following high values are above the normal from the sixth to the nineteenth day, they are below the normal before the sixth day; and those corresponding to mean "solar-constant" values differ by little from the normal through the whole interval.

The dependence of temperature upon solar radiation is so well marked at Buenos Aires that Mr. Clayton is of the opinion that the fluctuations there from mean or normal conditions that we speak of as "weather" as opposed to "climate" may depend principally upon the variability of the sun. This is a very bold statement, but Mr. Clayton has collected much evidence in support of it. One of the most striking parts of this evidence is represented in the accompanying figure, just referred to, which is reprinted from the introduction to an article by Mr. Clayton published by the Smithsonian Institution.

The objection may be raised that changes in terrestrial temperature associated with changes in the observed values of the solar constant of radiation are not necessarily confirmatory of the actual existence of changes in the emission of radiation by the sun. It might be possible that peculiar conditions of the atmosphere would introduce errors in the determination of the solar constant at the same time that they led to changes in terrestrial temperature, barometric pressure, and rainfall. It must be replied, however, that the probability is very small that close correlation would be found between the supposed erroneous observations of the sun made at Mount Wilson, California, and the temperatures of Buenos Aires, situated at a vast distance and separated by 70° in latitude and 60° in longitude. It seems far easier to suppose that the real variations in the sun as determined by the observers at Mount Wilson are reflected in the terrestrial weather at all parts of the earth.

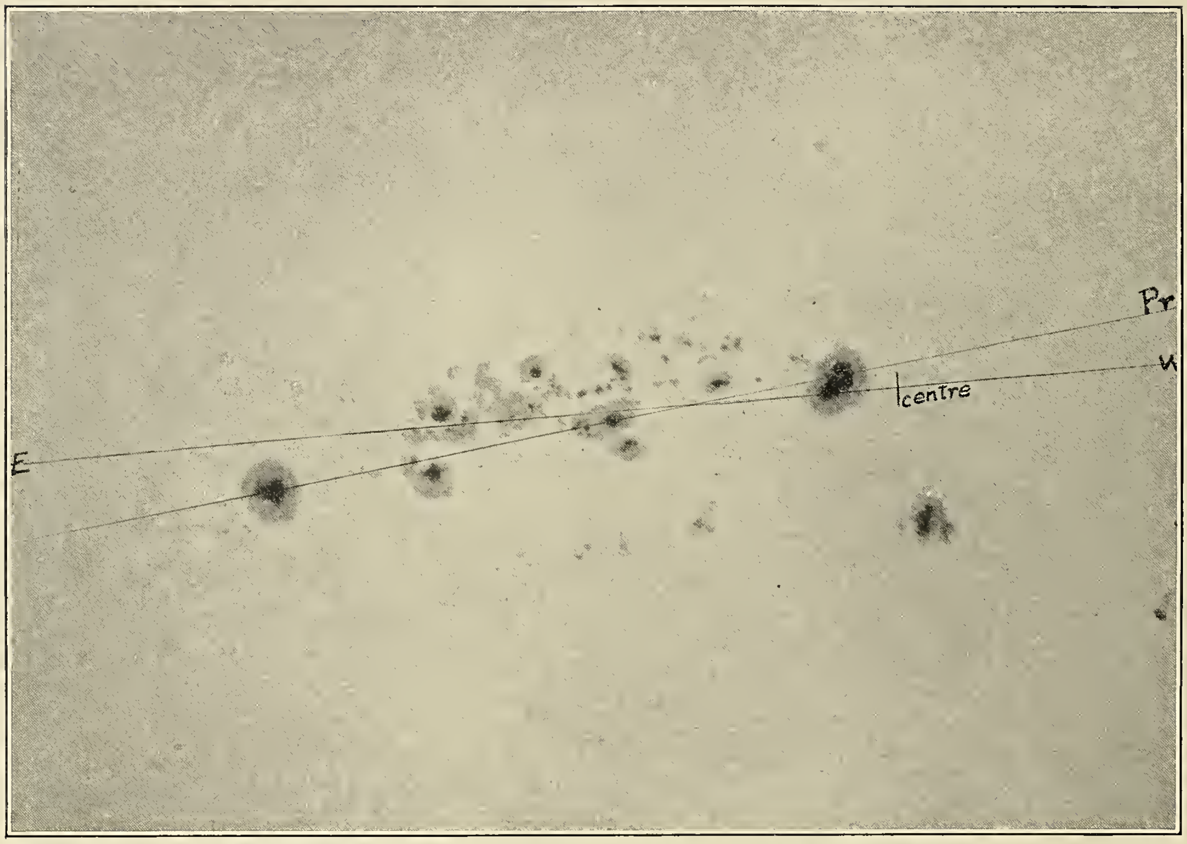
4. ASSOCIATION OF FLUCTUATIONS IN THE FRAUNHOFER LINES OF THE SOLAR SPECTRUM AND IN OTHER SOLAR PHENOMENA WITH VARIATIONS OF SOLAR RADIATION.

Mr. A. F. Moore, while director of the observing station at Calama, made preliminary investigations of the intensity of absorption revealed in the Fraunhofer lines as measured upon energy curves of the solar spectrum. His measurements relate to the more prominent lines of the elements hydrogen, calcium, magnesium, and iron. He finds that increased absorption apparently takes place by these gases in the solar envelope attending the decreased values of the solar constant of radiation. The investigation was broken off by building operations and by Mr. Moore's return to the United States, but the results appear to be so definite that Mr. Moore is in hopes that when he resumes it, means may be found for determining the changes of the solar constant of radiation by merely examining the intensity of the Fraunhofer lines in the solar spectrum. Such determinations could perhaps be made on cloudy days as well as on fair ones by photographic methods. This, however, must be confirmed by future work.

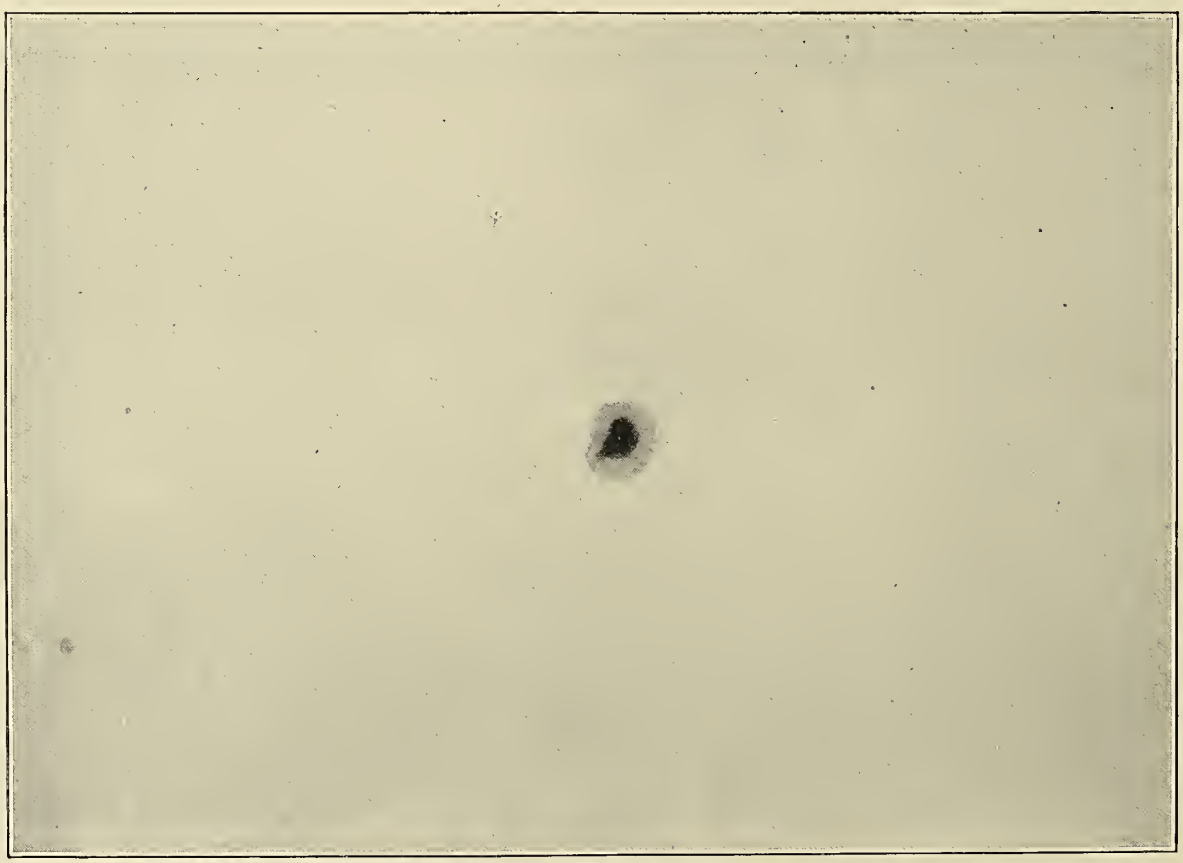
On March 22, 1920, at the time of central passage of a very large group of sun spots across the solar disk, a remarkable auroral display attended by terrestrial magnetic storms was reported in the daily press. It is very interesting to note the march of solar radiation about this time as reported by the Smithsonian observers at Calama, Chile. Their results were as follows:

Date, March	11-17	18	19	20	21	22	23	24	25	26	27-31
Solar constant	*Mean.* 1.957	1.936	1.930	1.922	1.920	1.923	1.846	1.887	....	1.934	*Mean.* 1.961

THE SUN, MARCH 20, 1920. MOUNT WILSON SOLAR OBSERVATORY, 6H:52M A. M.



1. SUN-SPOT GROUP, MARCH 20, 1920. MOUNT WILSON, 6H: 52M A. M.



2. SUN-SPOT, APRIL 17, 1920. MOUNT WILSON, 9H: 03M A. M.

The profound depression of solar radiation of March 20 to 24 coincides approximately with the central passage of the sun-spot group, though at maximum the depression lagged behind the sun-spot group more than a day.

The spot group again became central on April 16. It had decayed to much less than its March importance and a comparison with the Calama solar-constant values is again interesting.

Date, April	10–14	15	16	17	18	19	20–25
Solar constant	*Mean.* 1.960	1.953	1.954	1.953	1.957	1.950	*Mean.* 1.951

The very slight depression of April 15 to 17 occurs very near the time of central passage of the sun-spot group but is hardly conclusively shown.

The accompanying illustrations, Plates I and II, are kindly furnished by the Mount Wilson Solar Observatory.

We hope, now that the Arizona and Chile stations are running steadily, that there will be occasional opportunities as favorable as that of March 22, 1920, to test the very plausible expectation that a central passage of extraordinary phenomena over the sun's disk should be attended by well-marked changes of the solar constant. This, if confirmed, will be in full harmony with the hypothesis of short-period solar variations as due to irregularities in the solar emission in different position angles, which irregularities as they rotate with the sun produce the observed variations.

In a paper entitled "On Periodicity in Solar Variation,"[2] which is reprinted in Appendix II, it very clearly appears that a periodicity approximating 25 days in length was well marked in the Mount Wilson solar-constant values of 1915, and appeared less prominently also in 1910 and 1916. This period comparable with that of the solar rotation is of course highly confirmatory of the real existence of solar variability of the type associated with irregularities of solar emission in different position angles.

5. CORRELATION BETWEEN VARIATIONS OF SOLAR RADIATION AND VARIATIONS OF TERRESTRIAL MAGNETISM.

In several publications, Dr. L. A. Bauer, of the Department of Terrestrial Magnetism of the Carnegie Institution, has indicated a correlation between the variations of the sun as determined on Mount Wilson and certain outstanding fluctuations of the several elements of terrestrial magnetism hitherto unexplained. The reader should refer to Dr. Bauer's publications on this subject.

[2] Smithsonian Miscellaneous Collections, vol. 69, no. 6, 1918.

6. VARIATIONS IN THE BRIGHTNESS OF THE PLANETS ASSOCIATED WITH VARIATIONS OF THE SOLAR RADIATION.

If the radiation of the sun is variable the planets must vary correspondingly. It is not necessary, however, that the corresponding variations of the planets should occur simultaneously. If the sun should grow uniformly more active all over its surface, then all the planets would tend to increase in their brightness correspondingly and simultaneously. But if, on the other hand, the envelope of the sun should be affected with regions of varying transparency, or if beyond the well-defined limits of the solar envelope there should extend protuberant masses of matter tending to absorb or scatter the sun's radiation, there would be a nonuniformity of distribution of the solar radiation within the celestial sphere. If, now, these protuberant masses or regions of special hindrance to the escape of the sun's radiation should rotate like other solar features in a period of 25 days or more, it would follow that the influence of these changes of radiation in their different modifications would reach the various planets at different times, depending upon their respective heliocentric longitudes.

According to this view of solar variation, it would be unnecessary to suppose that the changes occur with extreme rapidity on the sun, for changes of the amount of radiation received on the earth, for instance, might succeed one another with great rapidity merely because of the passage in rotation of the various radially directed modifications of intensity of the solar beam. These modifications themselves might be of a fairly long continued existence so that they might even return after a full solar rotation and repeat themselves in their terrestrial effects. Thus there is, on this hypothesis, no difficulty in admitting rapid changes in the solar constant of radiation as observed upon the earth.

The fact that a certain tendency to the repetition in variations of solar radiation at intervals of about one period of the sun's rotation was prominent in 1915 [3] tends to support this view of the case. The same sort of a tendency has been noted at other times, although seldom so distinctly as in 1915. Another fact tending to recommend this view is found in the marked depression of the solar radiation values coinciding closely with the central position of the great sun-spot group which was attended by strong auroras and magnetic disturbances on March 22–23, 1920. A similar depression in solar radiation values, although not nearly so marked, was indistinctly noted in April 15–18 when the group of sun spots returned to a central position, decidedly reduced in their size and number.

Very interesting observations of Saturn pertinent to this inquiry were made by Guthnick and Praeger at the Berlin-Babelsberg Observatory, January to May, 1920, and privately communicated by Dr. Guthnick. Saturn was compared with

[3] On Periodicity in Solar Variation, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 69, no. 6, 1918.

α Leonis by means of a photoelectric cell. The differences of stellar magnitude, Saturn minus α Leonis, were corrected for solar distance, phase angle and ring effect, as well as possible. It is, however, impossible to use observations made within 1° of opposition, because the ring of Saturn brightens so rapidly at these small angles that proper allowance is not yet determined for it. There is a little uncertainty even for the phase correction outside these limits. Guthnick and Praeger's observations show that the phase coefficient for the east limb is greater than that for the west, and they give $0.^{m}025$ for its value for phase angles from 1° to 6° before opposition and $0.^{m}037$ for those from 1° to 6° after opposition.

We now give Guthnick and Praeger's observations, and the solar observations made at Calama available for comparison with them, together with such additional data as are needed to institute a test between the two hypotheses of solar change stated above.

TABLE 51.—*Comparison of Calama solar-constant results with Guthnick's Saturn observations of 1920.*

Date.	Guthnick original.				Phase correction.	Corrected Saturn minus α Leonis.	Time correction for solar radiation.[1]	Calama observations.				Solar radiation.	
	Greenwich mean time.	Saturn minus α Leonis.	Number of comparisons.	Phase angle.				Date, 1920.[2]	Solar radiation.	Date, 1920.[2]	Solar radiation.	Guthnick date.	Corrected date.
1920.	d.	m.		°	m.	°	d.						
Jan. 29	.598	+0.743	6	3.18	0.079	+0.664	−1.99	Jan. {29.05 30.05	1.959 1.968	Jan. {27.05 28.05	1.959 1.957	1.964	1.958
Feb. 8	.589	0.715	3	2.16	.054	.661	1.31	Feb. {8.05 9.05	1.945 1.960	Feb. 7.05	1.931	1.953	[3] 1.931
14	.461	0.704	4	1.53	.038	.666	1.19	Feb. 14.35	1.932	Feb. 13.35	1.955	1.932	1.955
16	.537	0.701	4	1.30	.032	.669	0.76	Feb. 16.05	1.953	Feb. 15.35	1.942	1.953	1.942
17	.542	0.690	3	1.18	.029	.661	0.69	Feb. 18.05	1.961	Feb. 17	....	1.961	....
18	.553	0.687	4	1.07	.027	.660	0.62	Feb. {18.05 19.05	1.961 1.959	Feb. 18.05	1.961	1.960	1.961
19	.537	0.681	4	0.96	.024	.657	0.56	Feb. {19.05 20.35	1.959 1.967	Feb. 19.05	1.959	1.963	1.959
23	.517	0.637	4	0.53	....	....	0.28	Feb. 24.35	1.957	....	....	....	....
25	.508	0.633	5	0.34	....	....	−0.13	Feb. 25.05	1.969	....	....	....	....
		Opposition.											
28	.513	0.614	5	0.25	....	....	+0.06	Feb. 28.35	1.943	....	....	....	....
Mar. 1	.499	0.653	5	0.40	....	....	0.19	Mar. {1.35 2.05	1.973 1.979	....	....	....	....
9	.509	0.711	4	1.26	.047	.664	0.74	Mar. 10.05	1.949	Mar. 10.05	1.949	1.949	1.949
13	.475	[4] 0.708	3	1.70	.063	.645	1.01	Mar. {13.05 14.05	1.945 1.953	Mar. {14.05 15.05	1.953 1.969	1.949	1.961
24	.409	0.783	......	2.85	.105	.678	1.75	Mar. 24.05	1.887	Mar. 26.05	1.934	1.887	1.934
25	.469	0.784	......	2.96	.110	.674	1.82	Mar. 25	....	Mar. 27.05	1.969	....	1.969
Apr. 12	.417	[5] 0.854	......	4.54	.168	.686	3.02	Apr. 12.05	1.962	Apr. 15.05	1.953	1.962	1.953
23	.393	0.860	......	5.27	.195	.665	3.75	Apr. 23.05	1.950	Apr. 27.05	1.955	1.950	1.955
May 11	.372	0.899	......	6.04	.223	.676	4.94	May 11.05	1.971	May 16.05	1.963	1.971	1.963
16	.369	0.896	......	6.14	.227	.669	+5.26	May 16.05	1.963	May {21.05 22.05	1.936 1.939	1.963	1.937

[1] Sun assumed to rotate 14.2° per day.
[2] Greenwich mean time; approximate.
[3] Cirro-cumuli over most of the sky at Calama.
[4] Uncertain; progressive change of sky; deserves no weight.
[5] Measures after Mar. 25 are all at considerable zenith distances, and the uncertainty of differential atmospheric extinction rapidly augments.

We have plotted these results in figures 13 and 14. In figure 14 the solar-constant results for the Greenwich date given by Guthnick are employed, interpolating when necessary between those made nearest in point of time. In figure 13 the values of the solar constant are taken with allowance for the solar rotation. In both figures we have omitted values taken when Saturn was well within 1° of opposition, and have omitted March 13, stated by Guthnick to be of little weight because of poor sky. Furthermore, we have marked with a dash below each observation made after March 25, for Guthnick states that with Saturn low in the heavens and the comparison star somewhat distant, these observations are less reliable. One of them, indeed, April 12, falls so far off as to be outside the limits of the plot, and is therefore omitted. We have also omitted the solar-constant value of February 7, marked unsatisfactory and observed when the sky was much overcast with cirro-cumuli at Calama.

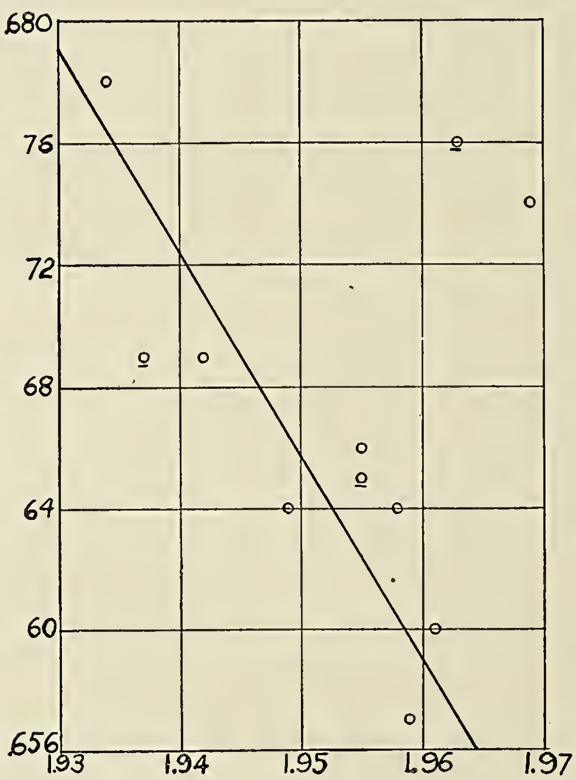


FIG. 13.—Variations of the sun and Saturn. First hypothesis.

On figures 13 and 14 we have drawn the line which corresponds to the theoretical change of brightness of Saturn, that is, $0.^{m}01$ increase of Saturn's stellar magnitude for 0.0180 calories per square centimeter per minute decrease of the solar constant. Neglecting values of small weight designated by dashes beneath them in the figure, all the points of figure 13, except that for March 25–27, agree as well as could be hoped with the theoretical line. The average deviation of the remaining solar-constant values is but 0.004 calories or 0.2 per cent. March 25–27, however, is a point of the highest weight at Calama, and Dr. Guthnick says nothing against it from his point of view. One explanation of its divergence is perhaps plausible. There is about 0.3 day difference in time between the Calama observation and the computed time to correspond with Guthnick's observation, allowing for solar rotation. The observation followed directly after the great depression of the solar constant accompanying the enormous sun-spot group of March, 1920. An increase of 0.035 calorie occurred in the solar constant in the 24 hours next preceding the discrepant observation. Possibly, therefore, an outlying solar streamer accompanying the main outburst caused Saturn during Guthnick's observation to be less bright than it would have been at the time corresponding to the Calama observation.

Turning now to figure 14, when the observations are plotted using identical dates, the points lie so scattered that hardly any correspondence exists between them and the line of theoretical correlation. We are, therefore, guided toward the hypothesis of rapid solar variation as dependent on the solar rotation carrying modifications of transparency with it, rather than a solar variation visible simultaneously from all the planets.

Further observations of Saturn at succeeding oppositions, and possibly an expansion of them to other planets, if any others are available where the local causes of variation can be satisfactorily allowed for, will, it is hoped, at length definitely prove whether or not the hypothesis we have just described is the true

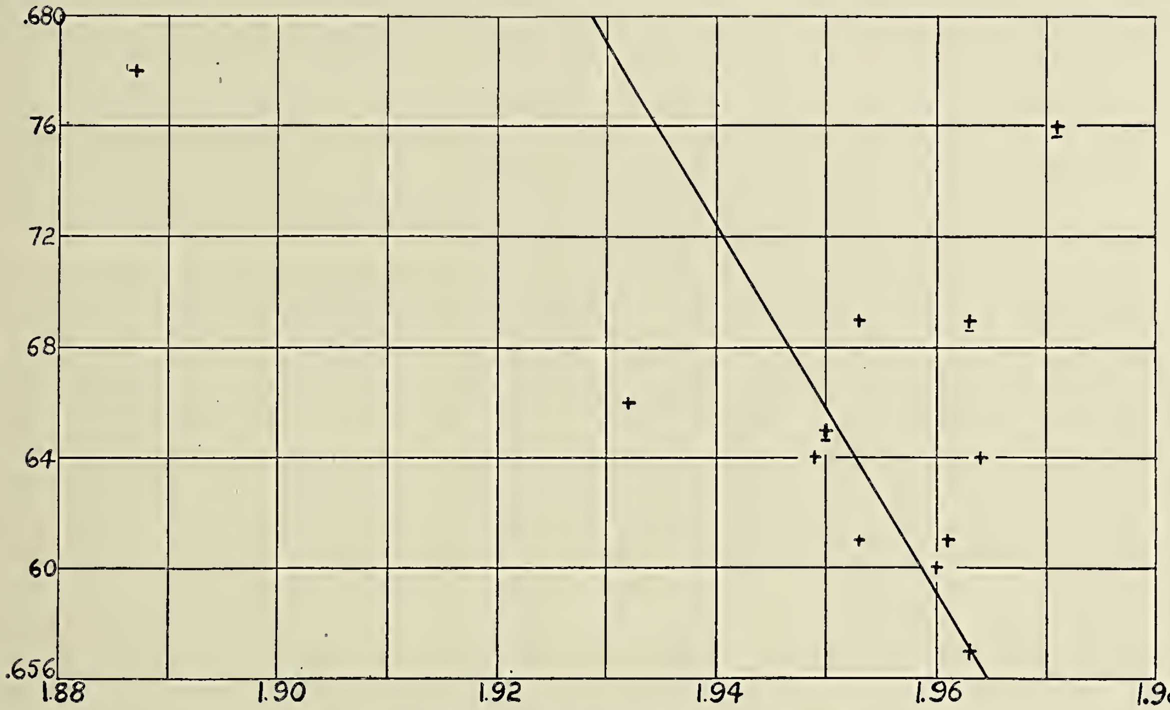


Fig. 14.—Variations of the sun and Saturn. Second hypothesis.

one. Its reasonableness, however, and the several lines of evidence which have been mentioned, go far already toward its establishment.

If we admit that a principal cause of the short-period irregular variability of the sun is due to the existence of regions of different transparency lying in different directions radially from the sun, then we may no longer expect that a comparison between the solar radiation values and the studies of the changes of distribution of radiation over the sun's disk, such as have been carried on from 1913 to the present time at Mount Wilson, would yield a close correlation. For whereas the existence of a region at the center of the sun's disk of unusually great transparency would tend to an increase of the solar constant of radiation observed on the earth, it might also serve to increase the contrast of brightness between the center and the edge of the sun if it was local to the center of the disk and did not extend to the limbs. If, on the other hand, the area of increased transmission should extend over the whole of the sun's visible hemisphere, it would produce a more marked effect near the limbs where the thickness of the supposed more transparent medium is greatest and the contrast could be diminished. Thus we see that depending on the distribution of these regions of greater or less transparency as they extend radially out from the sun, there would be fluctuations in the correlation between the solar constant of radiation and the distribution of solar radiation along the diameter of the disk, such as would make a comparison of the two kinds of measurement very disappointing as affording mutual proof of the sun's variability.

Something like this appears in fact to be shown by the results. There is a partial correlation between the variations of contrast and the variation of total radiation, but it is so imperfect as seldom to furnish very strong evidence of the solar variation. In view of these considerations, the only ways which now seem promising for actually testing and following accurately the sun's variability are, first, the establishment of several excellent solar-constant stations widely separated in the most cloudless regions of the earth, and, second, comparisons of their results with photometric observations of the brightness of the planets.

II. THE MEAN VALUE OF THE SOLAR CONSTANT OF RADIATION.

On page 134 of Volume III of the Annals we stated the mean result of the investigations up to and including part of the year 1912. The value indicated for the solar constant for the epoch 1902 to 1912 was 1.933 calories (15°) per square centimeter per minute.[4] In continuation of the work as there reported, we give the following table, which includes a summary of all of our new data on the solar constant of radiation as obtained at Mount Wilson and Calama up to the end of their occupation in the year 1920.

Taking the mean of all the results but those at Hump Mountain given in the following table and giving each single observation equal weight with every other, we obtain as the mean value of the solar constant of radiation for the epoch 1912 to 1920 determined by our 1,244 observations:

1.946 calories (15°) per square centimeter per minute.

This value is decidedly above the mean value, 1.933, for the epoch 1902–1912, and the higher value of it is doubtless to be attributed to the fact that a considerable part of the new period of observation has been an epoch of great solar activity. Indeed, the intensity of solar activity as measured by sun spots reached a higher level in the year 1917 than it had previously reached since the year 1870.

In regard to the absolute value of the solar constant of radiation, we must admit the criticism of Kron.[5] He points out that our work is somewhat faulty in the ultra-violet owing to the stray light which is scattered there, so that our transmission coefficients in that region of the spectrum are doubtless too high, and thus the increase of intensity of that part of the spectrum as between the observer and

[4] A slight error occurred in the computation of the general mean originally.

[5] E. Kron, Vierteljahrsschrift der Astronomischen Gesellschaft, 49, 53, 1914.

outside the atmosphere as we determine it is somewhat too low. He is of the opinion that our values of the solar constant are rendered on the whole 1 or 2 per cent low by this cause, and we are willing to agree that there may be an error of this nature. It has been inconvenient to us to introduce appliances to correct this small source of error in the ultra-violet, and as we have felt that it is not serious as an obstacle to determinations of the variations of the sun, and also not serious in itself as an error in our determination of the absolute value of the solar constant of radiation, we have given it less attention than some critics might think it deserves.

TABLE 52.—*Solar-constant values—Summary 1912–1920.*

Station.	Date.	Number.	Mean value.
Mount Wilson...........	1912, May–Sept...........	90	1.9461
	1913, July–Nov............	78	1.9044
	1914, June–Oct............	86	1.9570
	1915, June–Oct............	103	1.9519
	1916, June–Oct............	85	1.9458
	1917, July–Oct............	63	1.9589
	1918, June–Oct............	56	1.9476
	1919, June–Sept...........	64	[1] 1.9505
	1920, July–Sept...........	42	1.9307
Hump Mountain........	1917, June–Dec...........	41	[2] 1.9186
	1918, Jan.–Mar............	15	[2] 1.9269
Calama....................	1918, July–Dec............	116	1.9464
	1919, Jan.–Dec............	285	1.9474
	1920, Jan.–July............	176	1.9507

[1] An increase of 2.2 per cent has here been made in this value, as explained elsewhere.

[2] The Hump Mountain values are of such inferior weight that they are omitted in the general mean.

TABLE 53.—*Mean results of solar-constant observations, Mount Wilson, 1905–1920, by months.*

Date.	Number of days.	Atmospheric transmission at different wave lengths.										Solar constant.		Wolf-Wolfer sun-spot Nos. (unsmoothed).
		μ 0.35	μ 0.40	μ 0.45	μ 0.50	μ 0.60	μ 0.70	μ 0.80	μ 1.00	μ 1.20	μ 1.60	E_o.	E'_o.	
May:														
1906....	6	....	0.752	0.817	0.854	0.898	0.927	0.941	0.952	0.955	0.957	1.920	1.947	58
1908....	9	....	.705	.783	.832	.860	.915	.944	.954	.959	.970	1.915	1.934	41
1910....	12	0.609	.734	.803	.860	.893	.941	.961	.976	.973	.975	1.890	1.916	22
1912....	16	.575	.705	.786	.833	.865	.916	.939	.953	.956	.959	1.928	1.942	4
June:														
1905....	9	....	.743	.812	.854	.912	.946	.966	.981	.984	.987	1.939	1.968	49
1906....	12	....	.755	.822	.859	.906	.937	.953	.968	.973	.978	1.907	1.940	63
1908....	20	....	.711	.783	.829	.857	.907	.930	.946	.949	.962	1.923	1.944	48
1909....	22	....	.715	.799	.838	.870	.924	.947	.958	.958	.966	1.889	1.930	23
1910....	22	.614	.731	.811	.874	.904	.952	.973	.983	.977	.978	1.912	1.933	12
1911....	17	.591	.712	.796	.852	.879	.938	.962	.969	.969	.969	1.931	1.945	2
1912....	23	.589	.719	.803	.851	.886	.935	.957	.968	.971	.973	1.916	1.930	4
1914....	14	.565	.714	.800	.842	.873	.929	.953	.970	.975	.979	1.934	1.954	11
1915....	14	.593	.727	.808	.859	.888	.944	.966	.977	.980	.981	1.927	1.942	70
1916....	9	.591	.729	.807	.858	.890	.938	.959	.973	.977	.978	1.926	1.949	68
1918....	5	....	....	....	....	....	....	....	....	....	....	1.915	1.943	76
1919....	14	.636	.740	.804	.850	.884	.938	.961	.975	.979	.984	1.944	1.957	108

TABLE 53.—*Mean results of solar-constant observations, Mount Wilson, 1905–1920, by months*—Continued.

Date.	Number of days.	Atmospheric transmission at different wave lengths.										Solar constant.		Wolf-Wolfer sun-spot Nos. (unsmoothed).
		μ 0.35	μ 0.40	μ 0.45	μ 0.50	μ 0.60	μ 0.70	μ 0.80	μ 1.00	μ 1.20	μ 1.60	E_o.	E'_o.	
July:														
1905....	12	....	0.719	0.792	0.839	0.897	0.932	0.951	0.967	0.972	0.977	1.941	1.972	73
1906....	11	....	.718	.791	.836	.888	.923	.941	.957	.964	.972	1.918	1.962	103
1908....	20	....	.703	.793	.839	.869	.924	.943	.956	.961	.966	1.905	1.935	40
1909....	23	0.660	.747	.817	.864	.892	.938	.955	.963	.960	.969	1.884	1.911	36
1910....	15	.633	.740	.816	.867	.895	.940	.961	.973	.972	.970	1.881	1.898	14
1911....	16	.614	.745	.807	.860	.890	.943	.964	.976	.977	.981	1.899	1.917	3
1912....	20	.513	.637	.717	.769	.813	.868	.901	.926	.936	.944	1.941	1.950	3
1913....	3	....	....	....	....	....	....	....	....	....	....	1.902	1.928	2
1914....	14	.571	.715	.804	.852	.880	.934	.955	.969	.972	.977	1.930	1.959	5
1915....	22	.593	.735	.821	.868	.898	.950	.968	.980	.983	.986	1.926	1.947	71
1916....	25	.596	.732	.811	.858	.891	.943	.963	.975	.977	.980	1.926	1.947	53
1917....	12	.539	.672	.761	.815	.852	.909	.935	.953	.959	.967	1.954	1.989	117
1918....	18	.576	.711	.796	.848	.877	.936	.960	.972	.975	.976	1.927	1.954	105
1919....	18	.618	.723	.791	.839	.879	.926	.949	.969	.974	.983	1.917	1.950	64
1920....	17	.634	.739	.821	.873	.897	.948	.972	.983	.981	.988	1.899	1.925	26
August:														
1905....	16	....	.731	.803	.850	.898	.937	.956	.971	.975	.979	1.905	1.955	59
1906....	13	....	.737	.804	.845	.899	.932	.951	.967	.974	.980	1.910	1.943	48
1908....	29	....	.695	.786	.833	.869	.920	.942	.954	.955	.957	1.921	1.951	90
1909....	19	.636	.734	.808	.858	.890	.938	.956	.966	.962	.972	1.890	1.926	23
1910....	23	.625	.713	.814	.867	.898	.944	.966	.971	.969	.974	1.873	1.912	12
1911....	27	.633	.743	.818	.874	.903	.957	.973	.976	.979	.977	1.917	1.929	4
1912....	27	.496	.611	.682	.730	.771	.822	.850	.889	.904	.921	1.933	1.957	0
1913....	19	.546	.679	.761	.810	.845	.905	.932	.954	.961	.966	1.915	1.940	0
1914....	24	.561	.712	.801	.848	.880	.936	.952	.966	.971	.976	1.939	1.966	8
1915....	27	.583	.723	.811	.861	.895	.947	.966	.979	.981	.985	1.934	1.951	69
1916....	19	.585	.711	.782	.828	.867	.916	.944	.964	.971	.977	1.932	1.952	34
1917....	22	.579	.710	.788	.838	.871	.924	.948	.965	.969	.973	1.935	1.956	143
1918....	17	.574	.707	.788	.841	.863	.934	.958	.972	.975	.978	1.915	1.947	94
1919....	16	.617	.712	.781	.830	.869	.919	.943	.966	.970	.979	1.920	1.945	68
1920....	21	.605	.701	.779	.833	.867	.924	.954	.969	.969	.979	1.917	1.947	19
September:														
1905....	12	....	.726	.802	.846	.898	.934	.954	.969	.974	.977	1.894	1.930	55
1906....	10	....	.751	.818	.860	.912	.942	.957	.971	.975	.980	1.918	1.948	56
1908....	13	....	.713	.791	.845	.879	.932	.947	.951	.955	.961	1.896	1.935	87
1909....	14	.621	.739	.815	.875	.900	.954	.968	.980	.981	.983	1.885	1.908	39
1910....	21	.642	.742	.823	.873	.906	.953	.970	.981	.980	.973	1.896	1.910	26
1911....	18	.628	.738	.818	.876	.896	.951	.969	.977	.973	.977	1.928	1.938	4
1912....	4	....	....	....	....	....	....	....	....	....	....	1.948	1.962	9
1913....	25	.558	.693	.775	.824	.861	.919	.942	.960	.965	.971	1.900	1.918	1
1914....	21	.599	.738	.820	.866	.898	.948	.966	.978	.981	.985	1.923	1.945	13
1915....	19	.574	.716	.798	.850	.888	.942	.963	.973	.980	.984	1.945	1.968	45
1916....	21	.582	.705	.784	.838	.873	.924	.947	.965	.971	.978	1.926	1.942	41
1917....	22	.605	.730	.806	.852	.886	.939	.959	.971	.974	.978	1.924	1.948	122
1918....	11	.587	.722	.803	.856	.891	.943	.963	.973	.974	.978	1.938	1.959	73
1919....	17	.646	.746	.810	.855	.891	.936	.961	.977	.979	.985	1.925	1.944	52
1920....	5	.615	.712	.779	.830	.875	.930	.960	.978	.976	.985	1.883	1.913	39
October:														
1905....	10	....	.747	.823	.864	.909	.944	.963	.978	.983	.987	1.900	1.928	79
1906....	10	....	.757	.825	.866	.914	.947	.964	.977	.981	.984	1.902	1.918	58
1908....	17	....	.709	.788	.836	.879	.922	.943	.955	.954	.955	1.935	1.951	32
1909....	16	.618	.736	.820	.870	.910	.953	.970	.980	.979	.981	1.867	1.889	58
1910....	17	.640	.737	.809	.867	.898	.947	.970	.980	.980	.982	1.903	1.927	38
1911....	22	.640	.739	.827	.880	.906	.957	.972	.980	.978	.981	1.906	1.915	3
1913....	25	.583	.712	.795	.840	.872	.926	.949	.968	.974	.981	1.858	1.870	3
1914....	13	.606	.739	.817	.866	.902	.951	.969	.979	.982	.984	1.929	1.951	8
1915....	21	.578	.730	.818	.870	.902	.955	.974	.985	.987	.989	1.937	1.950	53

TABLE 53.—*Mean results of solar-constant observations, Mount Wilson, 1905–1920, by months*—Continued.

Date.	Number of days.	Atmospheric transmission at different wave lengths.										Solar constant.		Wolf-Wolfer sunspot Nos. (unsmoothed).
		μ 0.35	μ 0.40	μ 0.45	μ 0.50	μ 0.60	μ 0.70	μ 0.80	μ 1.00	μ 1.20	μ 1.60	E_o.	E'_o.	
October—Continued.														
1916....	11	0.582	0.710	0.791	0.849	0.884	0.936	0.958	0.972	0.977	0.981	1.921	1.937	56
1917....	7	.565	.712	.798	.848	.887	.940	.961	.974	.978	.980	1.925	1.951	71
1918....	5	....	....	....	....	....	....	....	....	....	....	1.934	1.961	86
November:														
1908....	7	....	.703	.794	.842	.880	.925	.941	.951	.954	.959	1.945	1.961	45
1909....	2	....	....	....	....	....	....	....	....	....	....	1.923	1.933	56
1910....	5	....	....	....	....	....	....	....	....	....	....	1.910	1.927	5
1911....	13	.642	.748	.831	.877	.911	.961	.982	.989	.984	.990	1.894	1.903	4
1913....	6	....	....	....	....	....	....	....	....	....	....	1.855	1.866	1

III. THE ATMOSPHERIC TRANSMISSION FOR VERTICAL HOMOGENEOUS RAYS.

In Volume III of the Annals we summarized all of the data at that time available for Washington, Bassour, Mount Wilson, and Mount Whitney. There is no occasion to repeat the data then given for any of these stations or to modify the general tenor even for Mount Wilson by the inclusion of extensive results of later work on the atmospheric transmission. It is well known from the researches of Dorno as well as our own that during the years 1912, 1913, and 1914 the atmospheric transparency was below the normal owing to the presence of dust from the volcanic eruption of Mount Katmai in Alaska on June 6, 1912. This turbidity of the atmosphere was largely cleared up before the end of 1913 and produced small, if any, deficiency in transparency during 1914 and 1915. Thereafter, as stated by Dorno, there is a slight decrease of atmospheric transparency for the years following 1915 which he attributes to solar causes. In order to show whether this effect is more marked in some parts of the spectrum than others, we have taken the monthly mean values of the transmission coefficients as determined at Mount Wilson for several regions of the spectrum for the years 1905 to 1920 and give them in the preceding Table 53. The results for August of all years, 1910 to 1920, are exhibited graphically in figure 15. The plot does not indicate a great difference in the march

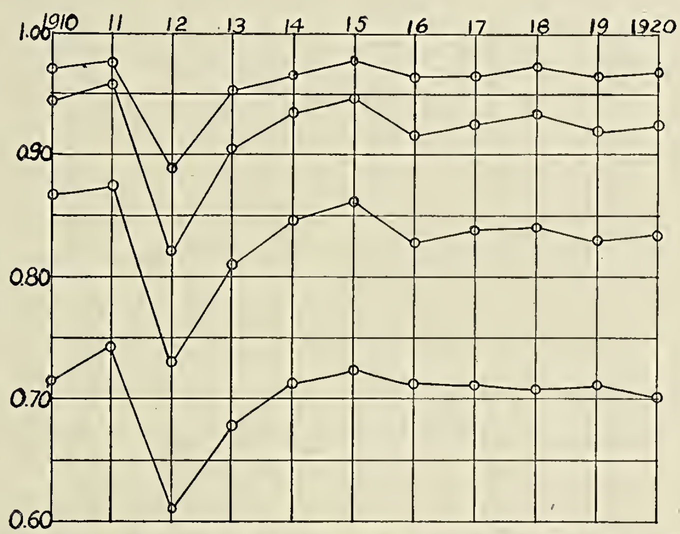


FIG. 15.—March of Mount Wilson atmospheric transparency. Selected wave lengths. 1912–1920. Ordinates: Transmission coefficients. Abscissae: Years. Wave lengths, reading upward, are 0.40, 0.50, 0.70, and 1.00 micron.

of the curves for wave lengths within the visible spectrum. The infra-red region, however, shows decidedly a less change from year to year.

It remains to give the transmission coefficients for the new stations, Hump Mountain, North Carolina, and Calama, Chile. The following (Table 54) gives characteristic results obtained at Hump Mountain in different seasons for the period June, 1917, to March, 1918. January 12, 1918, is particularly interesting because the observations were made at the low temperature of −22°C.

TABLE 54.—*Atmospheric transmission—Hump Mountain, N. C.*

Spectrum place.	Wave length.	1917					1918			Mean.
		June 30.	Aug. 26.	Sept. 18.	Oct. 22.	Nov. 18.	Jan. 12.	Feb. 11.	Mar. 18.	
	μ									
−235	0.346	0.559	0.595	0.510	0.534	0.560	0.614	0.555	0.595	0.565
230	0.350	.562	.605	.541	.540	.588	.614	.565	.605	.577
220	0.360	.588	.617	.587	.583	.613	.632	.585	.624	.604
210	0.371	.605	.640	.624	.598	.634	.651	.606	.646	.625
200	0.385	.648	.670	.655	.625	.670	.666	.626	.678	.655
190	0.397	.678	.718	.676	.683	.722	.670	.690	.688	.691
180	0.413	.704	.745	.722	.702	.748	.730	.702	.745	.725
170	0.431	.737	.756	.742	.721	.775	.743	.730	.772	.747
160	0.452	.764	.815	.788	.787	.813	.791	.756	.806	.790
150	0.475	.802	.843	.807	.810	.838	.840	.780	.836	.819
140	0.503	.825	.858	.830	.828	.855	.858	.805	.855	.839
130	0.535	.840	.867	.850	.835	.875	.885	.820	.875	.856
120	0.574	.864	.890	.864	.849	.890	.902	.830	.885	.872
110	0.624	.877	.897	.882	.871	.905	.929	.860	.904	.891
100	0.636	.908	.943	.921	.921	.942	.939	.900	.936	.926
95	0.722	.942	.950	.931	.926	.957	.945	.919	.946	.939
90	0.764	.934	.954	.946	.931	.966	.956	.936	.951	.947
85	0.812	.948	.965	.955	.939	.966	.964	.949	.959	.956
80	0.863	.954	.967	.962	.943	.971	.963	.952	.966	.960
75	0.922	.952	.970	.969	.948	.971	.966	.961	.963	.962
70	0.986	.950	.976	.968	.960	.974	.967	.968	.964	.966
65	1.062	.954	.975	.965	.957	.978	.968	.969	.966	.966
60	1.146	.940	.972	.966	.955	.978	.969	.965	.967	.964
55	1.226	.952	.970	.965	.959	.974	.968	.962	.966	.964
50	1.302	.950	.970	.964	.965	.969	.966	.953	.968	.963
45	1.377	.953	.972	.968	.964	.976	.957	.956	.968	.964
40	1.452	.966	.975	.975	.971	.979	.958	.960	.970	.969
35	1.528	.965	.986	.977	.973	.989	.949	.966	.974	.972
30	1.603	.979	.974	.980	.981	.990	.975	.975	.971	.978
25	1.670	.983	.981	.975	.973	.981	.986	.982	.981	.980
20	1.738	.983	.977	.975	.973	.977	.977	.983	.983	.978
10	1.870	.976	.975	.970	.972	.974	.981	.977	.978	.975
0	2.000	.969	.973	.979	.972	.977	.980	.973	.979	.975
+10	2.123	.984	.961	.979	.965	.868	.948	.957	.969	.966
20	2.242	.930	.970	.969	.944	.946	.958	.959	.965	.955

Table 55 gives the monthly mean atmospheric transmission coefficients at selected wave lengths as obtained in Calama, Chile, from July, 1918, to July, 1920.

Table 56 gives characteristic results at different seasons for all wave lengths observed.

We do not regard the Calama mean transmission coefficients of July, 1919, to July, 1920, as strictly accurate. Many of them represent mainly short-method

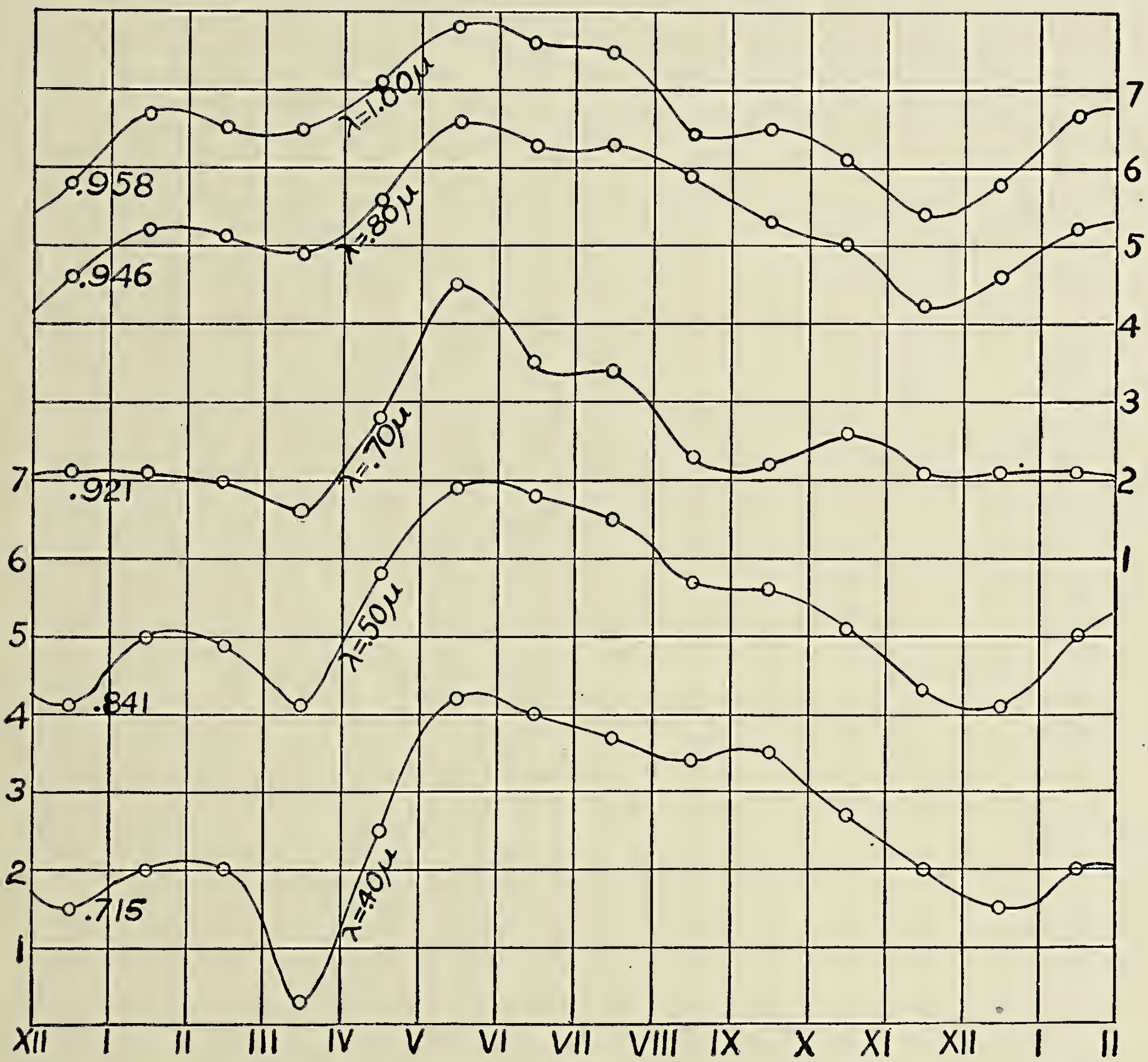


FIG. 16.—March ofmo nthly mean atmospheric transmission coefficients. Selected wave-lengths. Calama, August, 1918, to July, 1919. Roman numerals give the number of the month, I being for January.

observations, and as we have shown in Chapter V, the Calama short-method solar constants required small corrections on account of erroneous transmission coefficients. Hence we have computed Table 56 entirely from long-method observations.

Figure 16 gives graphically the march of the monthly mean transmission coefficients at Calama from observations of August, 1918, to July, 1919.

TABLE 55.—*Calama monthly mean atmospheric transmission coefficients, selected wave lengths.*

Wave lengths in μ........	0.35	0.40	0.45	0.50	0.60	0.70	0.80	1.00	1.20	1.60
July:										
1918, 5 days.....	607	723	808	851	887	927	957	968	967	973
1919, 27 days....	621	737	820	865	898	934	963	975	976	979
1920, 21 days....	617	735	821	867	900	934	962	975	976	979
August:										
1918, 27 days....	620	734	813	857	887	923	959	964	966	970
1919, 30 days....	618	732	816	862	895	931	961	974	974	978
September:										
1918, 18 days....	625	735	812	856	885	922	953	965	966	971
1919, 28 days....	617	729	814	860	894	929	959	973	973	977
October:										
1918, 18 days....	617	727	807	851	885	926	950	961	963	967
1919, 20 days....	608	721	805	851	887	924	954	969	969	973
November:										
1918, 21 days....	612	720	797	843	878	921	942	954	956	959
1919, 25 days....	607	722	791	853	888	923	955	969	970	973
December:										
1918, 19 days....	605	715	798	841	879	921	946	958	960	963
1919, 24 days....	586	698	783	830	870	904	936	952	952	957
January:										
1919, 19 days....	599	720	803	850	886	921	952	967	968	971
1920, 25 days....	582	697	780	828	869	899	931	947	948	953
February:										
1919, 20 days....	600	720	807	849	886	920	951	965	966	969
1920, 19 days....	584	697	780	827	868	898	933	948	950	955
March:										
1919, 15 days....	597	703	794	841	881	924	949	965	966	970
1920, 29 days....	591	704	788	834	874	906	941	954	957	961
April:										
1919, 27 days....	603	725	810	858	893	928	956	971	971	976
1920, 30 days....	605	720	806	852	888	922	956	969	970	974
May:										
1919, 26 days....	616	742	823	869	905	945	966	978	977	982
1920, 29 days....	616	733	818	863	897	931	960	973	974	978
June:										
1919, 22 days....	616	740	824	868	901	935	963	976	976	979
1920, 23 days....	622	738	824	869	901	936	963	976	977	980

TABLE 56.—*Atmospheric transmission, Calama, Chile.*

Spectrum place.	Wave length.	1918						1919						Mean.	High.			Low.		
		July 28.	Aug. 23.	Sept. 19.	Oct. 8.	Nov. 22.	Dec. 11.	Jan. 19.	Feb. 10.	Mar. 19.	Apr. 30.	May 12.	June 5.		Apr. 24, 1918.	June 1, 1919.	Mean.	Mar. 1, 1919.	Apr. 4, 1919.	Mean.
	μ																			
—235	0.346	0.579	0.607	0.611	0.598	0.583	0.596	0.592	0.587	0.608	0.599	0.598	0.608	0.597	0.608	0.607	0.607	0.548	0.533	0.540
230	.350	.605	.615	.627	.617	.603	.620	.612	.602	.615	.611	.612	.616	.613	.632	.621	.626	.560	.553	.556
220	.360	.630	.636	.638	.637	.627	.638	.633	.631	.643	.633	.622	.637	.634	.658	.643	.650	.568	.574	.571
210	.371	.659	.675	.672	.661	.650	.662	.664	.659	.649	.658	.649	.672	.661	.678	.668	.673	.598	.598	.598
200	.385	.690	.698	.700	.683	.673	.686	.698	.685	.686	.695	.692	.697	.690	.714	.698	.706	.627	.637	.632
190	.397	.704	.732	.742	.723	.703	.722	.731	.719	.718	.729	.719	.730	.723	.746	.737	.741	.630	.671	.650
180	.413	.736	.756	.765	.746	.737	.752	.763	.746	.749	.761	.747	.755	.751	.781	.765	.772	.661	.698	.679
170	.431	.756	.785	.791	.776	.763	.775	.792	.782	.767	.791	.779	.791	.779	.805	.803	.804	.698	.723	.710
160	.452	.816	.811	.822	.805	.797	.805	.825	.807	.813	.818	.812	.822	.813	.836	.832	.834	.741	.758	.749
150	.475	.825	.831	.840	.820	.818	.829	.848	.830	.834	.843	.831	.846	.833	.863	.852	.857	.754	.792	.773
140	.503	.852	.859	.863	.855	.850	.855	.873	.852	.855	.873	.864	.867	.860	.885	.878	.881	.771	.818	.794
130	.535	.875	.870	.875	.864	.857	.864	.888	.859	.868	.884	.875	.877	.871	.893	.888	.890	.803	.840	.821
120	.574	.879	.878	.888	.869	.866	.875	.897	.872	.885	.883	.879	.894	.880	.900	.894	.897	.815	.848	.831
110	.624	.894	.896	.902	.891	.883	.892	.914	.890	.905	.904	.903	.913	.899	.924	.918	.921	.840	.871	.855
100	.636	.935	.930	.930	.924	.910	.924	.944	.924	.933	.944	.934	.944	.931	.949	.935	.942	.884	.904	.894
95	.722	.946	.940	.945	.936	.922	.935	.954	.932	.943	.953	.947	.959	.943	.962	.950	.956	.896	.917	.906
90	.764	.954	.948	.951	.946	.931	.945	.961	.944	.949	.960	.954	.964	.951	.966	.960	.963	.913	.924	.918
85	.812	.956	.954	.954	.951	.939	.953	.966	.952	.952	.966	.959	.968	.956	.974	.968	.971	.929	.934	.931
80	.863	.960	.958	.958	.955	.944	.957	.973	.959	.960	.970	.968	.971	.961	.980	.976	.978	.934	.940	.937
75	.922	.955	.961	.960	.958	.947	.958	.977	.961	.964	.973	.973	.977	.964	.986	.978	.982	.937	.943	.940
70	.986	.964	.965	.964	.962	.949	.961	.982	.966	.970	.974	.975	.979	.968	.984	.981	.982	.944	.948	.946
65	1.062	.953	.967	.966	.965	.950	.962	.981	.966	.971	.975	.976	.980	.968	.985	.981	.983	.945	.948	.946
60	1.146	.955	.967	.967	.966	.952	.962	.981	.968	.969	.975	.976	.981	.968	.985	.985	.985	.942	.950	.946
55	1.226	.954	.966	.968	.966	.957	.962	.980	.969	.971	.974	.976	.978	.968	.980	.985	.982	.944	.951	.947
50	1.302	.948	.964	.966	.964	.952	.963	.978	.968	.969	.976	.976	.980	.967	.979	.983	.981	.942	.949	.945
45	1.377	.958	.967	.967	.964	.954	.962	.979	.967	.969	.978	.978	.982	.969	.978	.981	.980	.942	.953	.947
40	1.452	.961	.969	.970	.968	.954	.964	.981	.969	.972	.975	.980	.984	.971	.979	.981	.980	.944	.955	.949
35	1.528	.971	.969	.971	.969	.956	.964	.982	.970	.970	.977	.981	.984	.972	.977	.982	.979	.939	.954	.946
30	1.603	.970	.970	.973	.969	.955	.946	.981	.970	.970	.980	.981	.981	.971	.984	.986	.985	.952	.955	.953
25	1.670	.961	.972	.972	.970	.956	.964	.982	.973	.969	.978	.980	.981	.971	.985	.986	.985	.953	.956	.954
20	1.738	.964	.970	.972	.969	.954	.963	.981	.973	.969	.980	.981	.979	.971	.986	.984	.985	.953	.956	.954
10	1.870	.963	.970	.971	.968	.952	.963	.985	.976	.968	.979	.982	.976	.971	.988	.983	.985	.951	.958	.954
0	2.000	.964	.969	.971	.966	.951	.966	.980	.977	.964	.976	.984	.974	.970	.987	.983	.985	.955	.960	.957
+10	2.123	.962	.967	.967	.964	.959	.958	.977	.976	.953	.973	.977	.963	.966	.984	.972	.978	.952	.968	.960
20	2.242	.960	.960	.955	.961	.953	.955	.970	.967	.953	.964	.972	.959	.961	.971	.966	.968	.947	.954	.950

IV. THE DISTRIBUTION OF ENERGY IN THE SOLAR SPECTRUM.

In Volume III of these Annals, page 197, we gave the results of investigations made to determine the form of the energy spectrum of the sun as it is outside the atmosphere. These investigations were made at Washington, Mount Wilson, and Mount Whitney under various conditions of prisms and reflecting mirrors which are enumerated in the publication. In the solar spectrum from 0.4 micron to 2 microns the results apparently give the distribution of intensity with a probable error of less than 2 per cent. But there is considerable range as between the different determinations, and we hoped, now that the spectroscope had been provided with stellite mirrors that we might be able to make the results still more certain. Our first trials with stellite have failed in this, but the cause of failure is so instructive that we give an account of the new work.

A statement of the method adopted for the observations may be found in Volume II of these Annals, pages 24 and 50-57. At each of a number of wave lengths in the solar spectrum it is required to determine: (1) The intensity in the spectrum as observed at the bolometer; (2) the selective transmission of the spectroscope; (3) the selective reflection of the coelostat; (4) the transmission of the atmosphere. The bolograph indicates the first, and the measurements on a series of bolographs taken at different zenith distances of the sun furnish the means of computing the last. The reflection of the coelostat is determined by taking bolographs (*a*) with the ordinary pair of mirrors, (*b*) with a substitute pair of mirrors, (*c*) with a combination of both regular and substitute mirrors. The relative transmission of the spectroscope is determined by first passing the rays through an auxiliary spectroscope, selecting certain wave lengths and observing their intensity, (*d*) as transmitted by the auxiliary spectroscope, (*e*) as transmitted by both spectroscopes.

The observation (*d*) is made by setting the bolometer to occupy the position usually occupied by the slit of the usual spectroscope. In this position a number of settings of the auxiliary spectroscope are made, so as to determine the intensity of its radiation at a sufficient number of wave lengths. Then the slit of the usual spectroscope is restored to its proper position so as to permit nearly monochromatic beams of light to pass through the usual spectroscope after having been sorted out by the auxiliary one. The relative intensities of these nearly monochromatic beams are determined by taking bolographic energy curves of them. The areas included in these bolographic energy curves give the relative amounts of energy remaining in these wave lengths after having suffered absorption in the usual spectroscope. Thus the galvanometer deflections with the bolometer at the slit divided by the areas of the corresponding energy curves formed by the bolometer in its usual position, give numbers proportional to the transmission of the usual spectroscope.

After the installation of the stellite mirrors in the spectrobolometer in July, 1916, determinations were made on three different days, making twelve independent determinations in all of the transmission of the stellite-ultra-violet-glass optical system. The individual determinations were in excellent agreement and great confidence was felt that the results of the determination were better than had ever before been obtained. Unfortunately a source of error had inadvertently been introduced. We had at that time recently installed a vacuum bolometer which was so connected with the air pump that it was impossible to move it from the usual position to the position of the slit. Accordingly we made the observations at the slit with the bolometer in air which had been employed in Algeria.

We had always assumed that since the absorption of lampblack for light is variously estimated from 97 to 98 per cent its absorption could be regarded as practically complete, and independent of the wave lengths in the spectrum which we investigated. It is, to be sure, well known that for very great wave lengths lampblack is less perfectly absorbing, but for the range from 0.3 to 3 microns we feared no error from neglecting any changes in its absorptive properties for different wave lengths.

When the results of the determinations of the form of the energy curve outside the atmosphere came to be worked out from the observations of 1916, 1917 and 1918, and for wave lengths from 0.3 to 0.5 μ, reduced to the same scale with the curve indicated in the Annals, Volume III, page 197, there appeared a large divergence in the infra-red, so that the newer results ran 25 per cent higher there than the old. Having searched for all possible sources of error, both in the old and in the new work, it at length occurred to us that possibly there might have been a difference in the absorptive powers of the two cooperating bolometers used in 1916 to determine the transmission of the spectroscope. Fortunately the means of testing this hypothesis were available, although not with that high degree of accuracy which we would have desired.

On June 27, 1919, Mr. Aldrich without changing the slit widths made bolographs of the solar spectrum alternately with the new vacuum bolometer of 1917 and the Algerian bolometer whose strips are in air. These observations were made to determine how much more sensitive the new vacuum bolometer is than the Algerian bolometer under identical spectrum exposures. While satisfactory for this rough determination, the deflections with the Algerian bolometer are too small for the more exacting use we now put upon them. The new vacuum bolometer of 1917 and the old vacuum bolometer of 1916 were both made with their sensitive strips painted with lampblack paint. Experiments indicate that they have similar relative absorption for different wave lengths. The Algerian and earlier bolometers were made with their sensitive strips smoked with camphor smoke. It may have occurred that the coating of lampblack made by smoking the strips of the older bolometers was sometimes too thin for complete absorption, especially in the infra-red, or it might have come about that parts of the strip had been made bare, either by particles flaking off or by at some time using too large an electric current and thus burning off the central part of the strip. Be the cause what it may, the comparative observations of June 27, 1919, indicate decidedly that there is a progressive difference in absorption of the two bolometers for different wave lengths. This difference is indicated as follows.

TABLE 57.—*Comparison of bolometers.*

Prismatic deviation from ω_1	250′	220′	191′	180′	170′	155′	150′	125′	115′	100′	67.5′	55′	35′	25′
Corresponding wave length μ	0.343	0.360	0.398	0.413	0.431	0.464	0.475	0.555	0.600	0.686	1.039	1.223	1.528	1.670
Galvanometer deflections:														
New vacuum bolometer	3.66	12.50	8.50	5.20	5.85	12.00	4.22	7.85	9.88	13.38	11.50	9.02	6.47	16.10
Algerian bolometer	.52	1.55	1.08	.76	.85	1.35	.48	.96	1.25	1.44	1.29	.97	.57	1.60
Ratio of sensitiveness	7.05	8.07	7.87	6.84	6.88	6.89	8.79	8.18	7.90	7.29	8.91	9.30	11.4	10.1

From this result[6] we appear to be justified in making a correction to the determination of the absorption of the spectroscope made in July, 1916. This correction as read from a smooth curve based on the above table has accordingly been introduced. The following table gives a determination of the form of the solar energy curve depending upon (*a*) the corrected transmission of the stellite-ultra-violet-glass spectroscope as determined by combining the results of 1916 with those just mentioned of 1919; (*b*) the reflection of the coelostat with stellite mirrors as determined in 1918; and (*c*) the form of the energy curve and the transmission of the atmosphere as determined for 12 excellent days of 1918.

Column 1 gives the wave length; column 2 the deviation from ω_1 in the ultra-violet-glass prismatic spectrum expressed in minutes of arc; column 3, the coefficient of dispersion $\frac{d\theta}{d\lambda}$ of the prism; column 4, the reflection of the coelostat; column 5, the corrected relative transmission of the spectroscope; column 6, the mean distribution of energy outside the atmosphere as computed from results of 12 days of experiment in 1918. Thus far all of the table depends on work with all stellite mirrors, including two in the coelostat and two in the spectrobolometer, and with the ultra-violet glass prism in the spectrobolometer. The three following columns include results of 1916 and 1917, in which the spectrobolometer was employed with stellite mirrors and the ultra-violet glass prism, but the mirrors of the coelostat were of silver on glass, and their transmission was independently determined on every day of observation. The results of 1916, given in column 7, are based on five days of observation, August 16, August 18, August 19, September 9, and October 18, in which the determinations were regarded as excellent, and those of 1917 on 10 days of observation, also regarded as excellent, but of which five days, whose mean result is in column 8, were days of high solar radiation, July 1, 4, 5, 6, 7; and five, whose mean is in column 9, were days of low values, July 8, August 17, 19, 20, 26. The mean value of the solar constant on the five high days was 2.014 and the mean value on the five low days was 1.939.

[6] The reader will note that the new vacuum bolometer exceeds in sensitiveness the Algerian bolometer by seven to ten fold.

TABLE 58.—*The solar spectrum energy curve.*

Wave length.	Prismatic deviation.	Dispersion coefficient.	Coelostat reflections.	Spectroscope transmission.	Results of 1918.	Results of 1916.	Results of 1917 (high).	Results of 1917 (low).	Ratio $\frac{H}{L}$	Mean, 1916, 1917, 1918.	Mean, 1903 to 1910.	New minus old, per cent.
μ												
0. 3415	240	1, 225	0. 268	151	2, 680	2, 870	2, 640	2, 330	1. 134	2, 630	2, 260	+16
. 3504	230	1, 104	. 275	192	3, 060	3, 260	3, 030	2, 800	1. 082	3, 040	2, 720	+12
. 3600	220	990	. 284	236	3, 450	3, 390	3, 170	3, 170	1. 000	3, 300	3, 100	+10
. 3709	210	887	. 294	277	3, 450	3, 690	3, 430	3, 540	. 969	3, 530	3, 420	+ 3
. 3853	200	788	. 304	270	3, 790	3, 920	3, 830	3, 880	. 987	3, 850	3, 440	+12
. 3974	190	692	. 314	281	4, 120	4, 150	4, 060	4, 130	. 983	4, 110	4, 130	− 0. 5
. 4127	180	605	. 324	310	5, 590	6, 030	5, 520	5, 550	. 995	5, 670	5, 060	+12
. 4307	170	529	. 336	342	5, 180	5, 380	5, 030	5, 140	. 979	5, 180	5, 350	− 3
. 4516	160	460	. 350	363	5, 860	5, 800	5, 710	5, 830	. 979	5, 800	6, 100	− 5
. 4753	150	397	. 364	372	6, 170	6, 340	6, 130	6, 250	. 981	6, 220	6, 250	− 0. 5
. 5026	140	338	. 378	396	5, 680	5, 700	5, 650	5, 600	1. 008	5, 660	6, 040	− 7
. 5348	130	282	. 392	434	5, 270	5, 380	5, 290	5, 250	1. 008	5, 300	5, 780	− 8
. 5742	120	230	. 406	446	5, 100	5, 130	5, 090	5, 000	1. 018	5, 080	5, 380	− 5
. 5980	115	206	. 414	452	4, 830	4, 870	4, 820	4, 780	1. 008	4, 820	....	....
. 6238	110	183	. 423	457	4, 520	4, 540	4, 490	4, 460	1. 007	4, 500	4, 720	− 5
. 6530	105	162	. 432	460	4, 250	4, 280	4, 160	4, 240	. 981	4, 230	....	....
. 6858	100	144	. 442	464	3, 930	3, 940	3, 880	3, 880	1. 000	3, 910	3, 840	+ 2
. 7222	95	127	. 451	459	3, 530	3, 560	3, 460	3, 500	. 989	3, 510	....	....
. 7644	90	112	. 461	449	3, 140	3, 140	3, 130	3, 130	1. 000	3, 130	2, 930	+ 7
. 8120	85	98. 8	. 469	429	2, 790	2, 810	2, 760	2, 780	. 993	2, 780	....	....
. 8634	80	86. 5	. 477	405	2, 430	2, 450	2, 420	2, 590	. 935	2, 470	2, 270	+ 9
. 9220	75	76. 8	. 485	383	2, 130	2, 140	2, 100	2, 120	. 991	2, 120	....	....
. 9861	70	71. 5	. 493	374	1, 868	1, 893	1, 859	1, 855	1. 007	1, 870	1, 720	+ 9
1. 0620	65	70. 0	. 502	378	1, 645	1, 656	1, 644	1, 645	1. 001	1, 647	....	....
1. 1460	60	66. 0	. 509	394	1, 372	1, 356	1, 341	1, 351	. 993	1, 355	1, 194	+13
1. 2255	55	66. 0	. 517	413	1, 198	1, 174	1, 167	1, 169	. 998	1, 177	....	....
1. 3019	50	66. 0	. 525	432	1, 014	1, 020	1, 005	1, 015	. 990	1, 013	894	+14
1. 3770	45	66. 0	. 532	454	876	885	857	868	. 987	871	....	....
1. 4520	40	66. 0	. 540	477	760	768	736	747	. 985	753	683	+10
1. 5285	35	66. 4	. 547	502	662	668	639	648	. 986	654	....	....
1. 6032	30	67. 3	. 554	527	554	596	550	562	. 979	565	523	+ 8
1. 6700	25	68. 1	. 562	541	487	526	498	497	1. 002	502	....	....
1. 7378	20	69. 6	. 570	546	434	472	445	452	. 985	451	420	+ 7
1. 8700	10	72. 3	. 588	534	335	375	266	271	. 982	312	329	− 5
2. 0000	00	76. 8	. 606	482	259	291	176	184	. 957	227	245	− 7
2. 1232	−10	83. 0	. 624	421	170	182	116	124	. 936	148	180	−17
2. 2416	−20	90. 5	. 642	350	116	122	120	121	. 992	120	139	−14
2. 3481	−30	100. 0	. 660	280	111	123	90	91	. 989	104	118	−12

In column 11 the general mean of the new results indicated is given and in column 12 the comparative results taken from the work of former years, which yielded smoothed values published in the Annals, Volume III, page 197. The final column, 13, of the table gives the differences between the old and the new curve in percentages. It will not be claimed for the new curve that it has as high weight as the old, for the reason that it depends on rather doubtful data in regard to the absorption of the spectroscope, as has been explained above. Apart from this weakness the new curve is very well supported by the close agreement of results of several years. In general it is seen that the agreement between the old and new results is fair considering the difficulty of the experiments. As between the two determinations of 1917, corresponding to high and low values of the solar constant respectively, the differences are so conflicting as not to lend conclusive support to the view that the shorter wave lengths are more affected than the longer ones by variations of the intensity of the radiation of the sun. Yet the ratio of high to low day's results (column 10) gives predominatingly higher values in the visible as compared to the infra-red regions of the spectrum. Further evidence follows.

V. FURTHER INVESTIGATIONS OF THE DEPENDENCE OF THE FORM OF THE SOLAR SPECTRUM ENERGY CURVE ON THE INTENSITY OF THE SOLAR RADIATION.

In Volume III of these Annals we gave on page 132 a table of results obtained at Bassour, Algeria, in the year 1912, chosen to indicate whether the distribution of the energy in the solar spectrum varies along with the variation of the solar constant of radiation. The question is, in other words, whether the rise and fall of intensity of the solar emission of radiation is proportional in all parts of the spectrum or whether the blue and violet end changes more than the red and infra-red end of the spectrum with these fluctuations. The work published in Volume III of the Annals, done at Bassour, Algeria, was unfortunately weakened by unfavorable sky conditions which prevailed in the year 1912, owing to the volcanic eruption of Mount Katmai in Alaska on June 6, 1912. The results, however, seemed to indicate that the change of the blue and violet end of the spectrum exceeded the change of the red and infra-red end when variations occurred in the solar constant of radiation.

It is possible that a departure in this sense might be due to terrestrial causes if the days selected happened to be days when the atmospheric transparency changed. For if we suppose that prevailingly low values of the solar constant occur on days when the sky is becoming more hazy, and prevailingly high values on days when the sky is becoming clearer, as certainly would be the case, the reader will readily see that there would be a tendency to produce larger errors for the violet end of the spectrum than for the red by such increasing haziness or such increasing transparency. It was thought possible, therefore, that a part or even all of the difference between energy curves corresponding to high solar constants and energy curves corresponding to lower solar constants might be due to atmospheric causes. The simultaneous occupation of Mount Wilson and Calama during 1918, 1919, and 1920 minimizes this objection. For we are able to select large groups of days when high and low solar-constant values were observed at both stations, and for these days to take the evidence of both stations independently as to whether the violet altered more than the red.

As explained in Volume III of these Annals, we were accustomed for several years to treat the form of the energy curve of the sun outside the atmosphere as if it were a fixed thing, and by assuming it to be fixed and knowing the losses in the atmosphere from the transmission coefficients derived for each day, we determined by difference the losses in the optical train. Now, however, with stellite mirrors we work differently. From determinations of the transmission of the optical train taken together with the knowledge of the transmission of the atmosphere on the day in question, and the form of the energy curve observed at the station at a given air mass, we determine for each day the form of the energy curve which would have been observed had we been outside the atmosphere altogether and with an apparatus of perfect transmissibility for all wave lengths.

Thus we had only to select for comparison from the years 1918, 1919, and 1920 days of satisfactory quality when high values and low values, respectively, had been observed at both Mount Wilson and Calama. The days chosen were as follows:

Year.	High.	Low.	Year.	High.	Low.
1918	Aug. 21	July 27	1919	Aug. 1	Sept. 2
	Sept. 1	July 29		Aug. 29	Sept. 17
	Sept. 16	Aug. 20	1920	July 12	Aug. 4
	Sept. 26	Aug. 29		July 26	Aug. 5
1919	June 21	July 2		Aug. 12	Aug. 14
	June 28	July 31		Aug. 13	Aug. 29
	July 29	Aug. 19		Aug. 17	Sept. 6

Using the weighted mean solar-constant values, where Calama determinations have weight 2, Mount Wilson weight 1, the mean solar-constant values for the groups are as follows:

Year	1918	1919	1920
High	1.970	1.971	1.959
Low	1.933	1.927	1.917
High minus low	0.037	0.044	0.042

Having reduced the energy curves outside the atmosphere for each group to the same scale in the most well-determined part of the spectrum, the mean energy curve was computed for each group, and the ratios of the mean values were taken in the sense high divided by low groups.[7] The results appear in Table 59 and in figure 17.[8] Notwithstanding some discrepancies, the general result seems to

[7] As stellite mirrors were not fully introduced at Calama until 1920, we can use Calama energy curves of that year only with complete confidence. But we ventured to employ June 28 and July 2, July 29 and 31, Aug. 29 and Sept. 2 of 1919 in pairs on account of the close proximity of these dates, for we thought it unlikely that the silvered coelostat mirrors could have changed much between the high and low days of these several pairs.

[8] As nearly twice as many energy curve distribution observations in all are available at Mount Wilson as at Calama, and as those at Calama for 1919 are of small weight on account of silvered coelostat mirrors, we include only Mount Wilson values in the figure.

be clearly in evidence, namely, high values of the solar constant are attended by a greater increase of energy in the shorter wave lengths than in the longer ones. This is as was expected. For in accordance with Planck's radiation formula an increase of solar temperature would produce a more rapid increase of radiation the shorter the wave length. Also, in accordance with terrestrial atmospheric analogy, a decrease of scattering in the solar envelope would increase the transmission more considerably the shorter the wave length.

As the effect is in the nature of a differentiation of the radiation with respect to some solar variable, perhaps effective temperature, perhaps scattering by particles small as compared to the wave length, and as in a combination of temper-

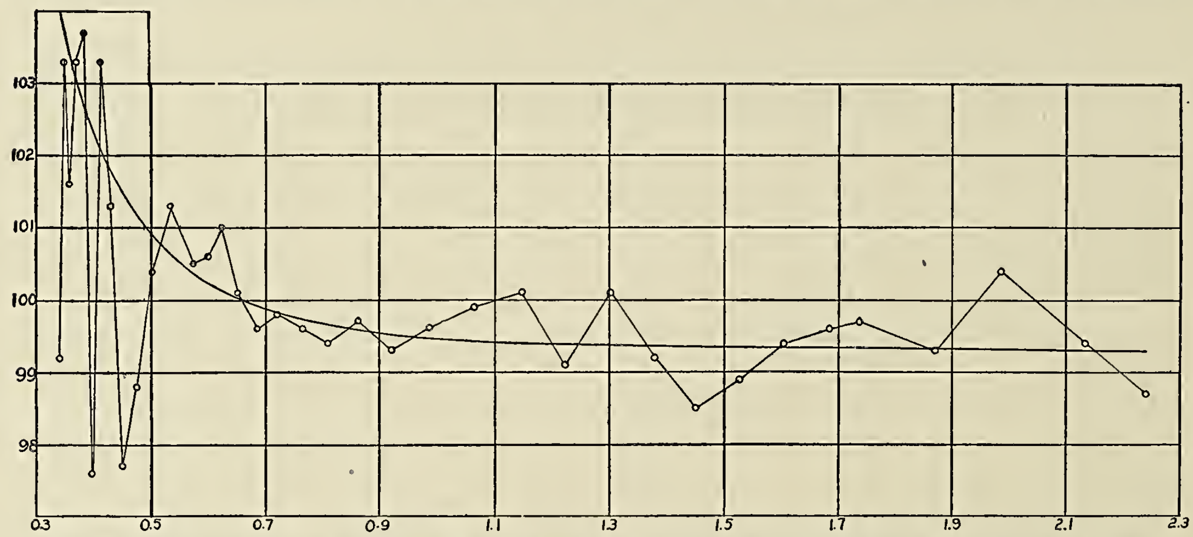


FIG. 17.—Change of energy curve with solar constant. Mount Wilson work. Ordinates: Percentage high to low. Abscissae: Wave-lengths μ.

ature and scattering effects a consideration of the formula of Planck for radiation and that of Rayleigh for scattering suggests as a mean approximately the fourth power of the wave length, of which the differential is the cube, it is interesting to compare the observational results graphically shown in figure 17 with the smooth curve given in the same figure whose ordinates increase inversely proportionally to the cube of the wave length. We do not attach much theoretical weight to the fair correspondence this curve shows to the observations. We do, however, regard the correlation shown between variations of the solar-constant values and variations of the distribution of energy outside the atmosphere, as determined at Mount Wilson and Calama independently, as constituting a new and valuable proof of the reality of short period solar variability.

TABLE 59.—*Variation of spectrum distribution with solar constant.*

Mount Wilson.				Spectrum place, minutes from ω_1.	Wave length, μ.	Calama.		
Ratios high to low.						Ratios high to low.		
Mean.	1918	1919	1920			1919	1920	Mean.
0. 992	1. 157	0. 922	0. 897	−240	0. 341	....	....	......
1. 033	1. 062	0. 982	1. 054	230	0. 350	0. 979	0. 980	0. 980
1. 016	1. 042	1. 000	1. 005	220	0. 360	1. 009	1. 017	1. 013
1. 033	1. 058	1. 050	0. 992	210	0. 371	1. 031	1. 015	1. 023
1. 037	1. 023	1. 027	1. 062	200	0. 385	1. 012	0. 982	0. 997
0. 976	0. 992	1. 003	0. 923	190	0. 397	0. 998	0. 994	0. 996
1. 033	1. 040	0. 998	1. 060	180	0. 413	1. 025	1. 012	1. 018
1. 013	0. 980	1. 049	1. 011	170	0. 431	1. 024	1. 011	1. 017
0. 977	0. 954	1. 000	0. 976	160	0. 452	1. 023	0. 978	1. 000
0. 988	0. 968	1. 009	0. 988	150	0. 475	1. 012	0. 982	0. 997
1. 004	0. 988	1. 017	1. 006	140	0. 503	1. 012	1. 003	1. 008
1. 013	1. 015	1. 020	1. 005	130	0. 535	1. 034	1. 016	1. 025
1. 005	0. 996	1. 012	1. 008	120	0. 574	1. 009	1. 019	1. 014
1. 006	0. 995	1. 015	1. 007	115	0. 598	....	....	......
1. 010	0. 996	1. 013	1. 021	110	0. 624	1. 004	0. 992	0. 998
1. 001	1. 002	1. 000	1. 000	105	0. 653	....	....	......
0. 996	0. 984	1. 011	0. 994	100	0. 636	1. 003	1. 000	1. 002
0. 998	0. 999	1. 008	0. 988	95	0. 722	0. 999	1. 000	1. 000
0. 996	1. 001	1. 000	0. 988	90	0. 764	1. 005	1. 001	1. 003
0. 994	1. 002	0. 989	0. 991	85	0. 812	1. 003	1. 011	1. 007
0. 997	1. 004	0. 980	1. 007	80	0. 863	0. 993	1. 002	0. 997
0. 993	0. 996	0. 977	1. 006	75	0. 922	0. 992	1. 010	1. 001
0. 996	0. 997	0. 992	0. 999	70	0. 986	0. 991	1. 004	0. 997
0. 999	1. 012	0. 993	0. 992	65	1. 062	0. 988	0. 998	0. 993
1. 001	1. 017	0. 993	0. 992	60	1. 146	0. 996	1. 000	0. 998
0. 991	1. 000	0. 975	0. 991	55	1. 226	0. 996	1. 004	1. 000
1. 001	1. 003	0. 989	1. 012	50	1. 302	0. 998	1. 006	1. 002
0. 992	0. 996	0. 996	0. 985	45	1. 377	0. 998	1. 002	1. 000
0. 985	1. 002	0. 995	0. 958	40	1. 452	1. 001	0. 985	0. 993
0. 989	1. 005	0. 996	0. 966	35	1. 528	0. 989	0. 978	0. 984
0. 994	0. 997	1. 005	0. 981	30	1. 603	1. 000	1. 006	1. 003
0. 996	0. 987	1. 015	0. 986	25	1. 670	1. 011	0. 992	1. 001
0. 997	0. 984	1. 017	0. 989	20	1. 738	0. 999	0. 997	0. 998
0. 993	0. 978	1. 013	0. 989	10	1. 870	1. 000	0. 986	0. 993
1. 004	0. 990	1. 012	1. 010	0	2. 000	0. 995	0. 959	0. 977
0. 994	0. 984	0. 990	1. 008	+ 10	2. 123	0. 981	0. 940	0. 961
0. 987	0. 982	0. 941	0. 937	20	2. 242	0. 959	0. 919	0. 937
0. 967	0. 953	0. 982	[1] 0. 848	30	2. 348	....	....	......

[1] Omitted in mean.

VI. PERIODICITY IN SOLAR VARIATION.

A paper on this subject is reprinted in the appendix to the present volume. The data shown there, which are the Mount Wilson solar-constant values of 1908 to 1916, were treated by the method of correlation coefficients as illustrated by Clayton.[9] That is, the solar-constant values of the successive days of a season's work were investigated for their correlation coefficients with values of the next day, the second day, the third, and so on up to the thirty-fifth day. The series of correlation coefficients were then plotted as ordinates against the days elapsed as abscissæ, and the resulting curves were examined for periodicity. A great dissimilarity appeared between the results of the different years. In several years, notably in 1915, indications of a periodicity associated with the solar rotation was observed. This was not unlooked for, and shows that if there is an inequality of radiation in different heliocentric longitudes, it is apt to persist for several rotations.

In further study of this subject, Mr. Fowle has employed the method used by several meteorologists for testing the existence of a suspected period of known length. That is, the Mount Wilson solar-constant data of each year, 1912 to 1920, were written down in lines of 28 days, the successive lines being superposed so that mean values representing the average march of the solar constant for the supposed 28-day period could be ascertained. In association with these solar-constant computations, he employed also the simultaneous Wolf-Wolfer daily sun-spot numbers. In both sets of data there were gaps for days when no observations were available. These gaps were not supplied except in a very few instances, so that in some cases the number of observations used in the mean values was very small. The data thus determined are plotted in the accompanying figure 18. In the plot for each year the upper curve is for solar-constant values, the lower curve for sun-spot numbers.

It will be seen that for several of the years, notably 1912 (for which three high values are in the upper margin), 1914, 1916, and 1917, there is a strongly marked indication of 28-day periodicity. In some years this seems to be closely correlated with the sun-spot frequency. But it is remarkable that while some of these apparent correlations are positive, others equally well marked are negative. In other years there is little or no 28-day periodicity at all. We have had several times to point out the same sort of an evanescent reversible correlation between the solar radiation and terrestrial and solar phenomena that could well be expected to be associated therewith. The influences are clearly very complex.

The observations of 1913 are treated for 25-day periodicity in figure 19.

In further study of the subject of periodicity in solar radiation, Mr. Aldrich has taken the corrected Calama solar-constant work of July, 1919, to July, 1920, which

[9] Smithsonian Miscellaneous Collections, vol. 68, no. 3, 1917.

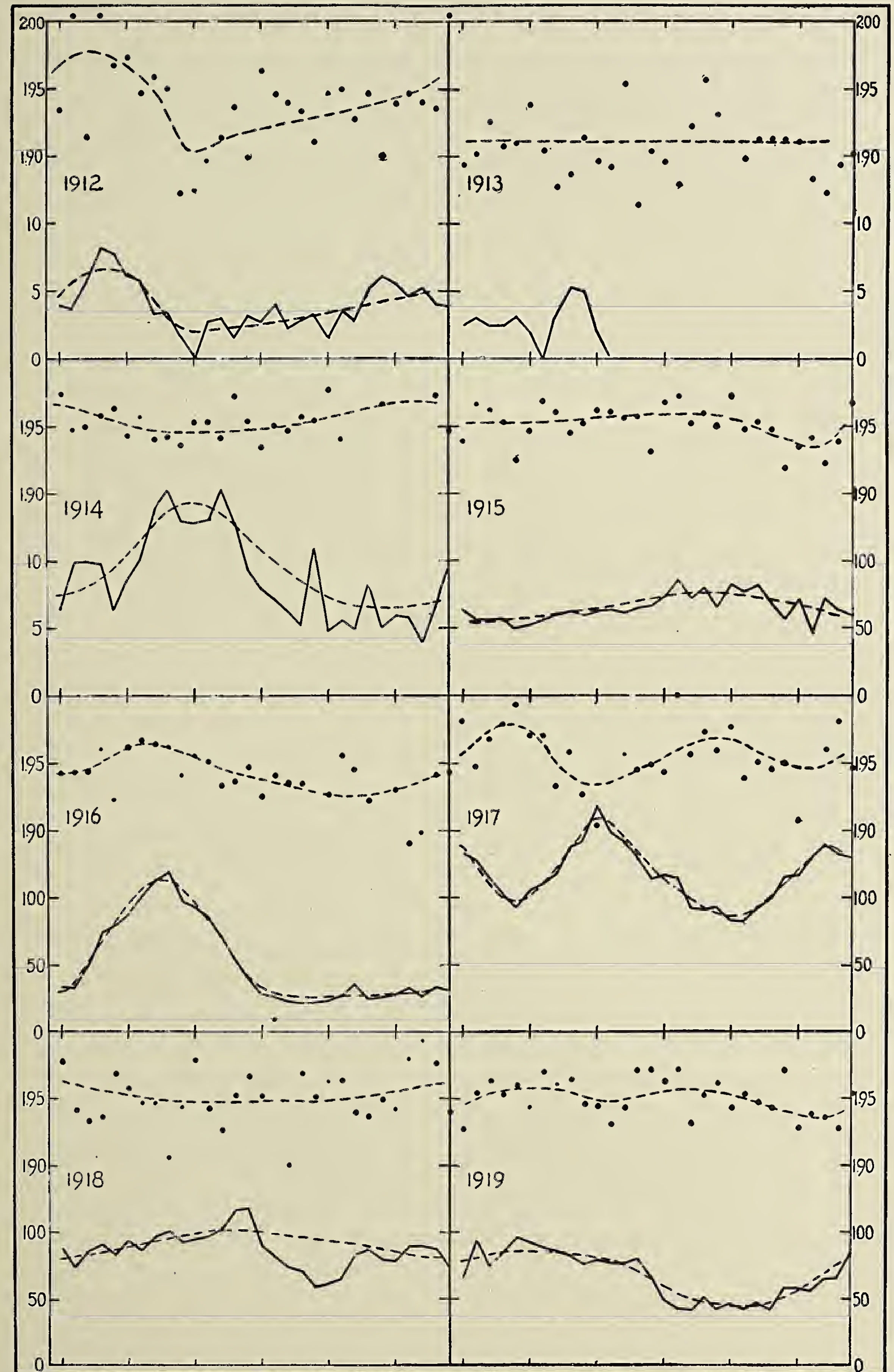


FIG. 18.—Twenty-eight day periodicity in solar observations.

we regard as the most accurate of all our series, and has treated it in the following manner designed to expose periodicities of any length under 35 days. The values were first written in a continuous column of successive days, vacancies being left for each of all the days not observed. On a movable slip the same data were written down a second time in the same manner. The movable slip was then displaced 1 day, 2 days, 3, etc., to 35 days upward, and the differences in the solar constants to the next, the second, the third, up to the thirty-fifth day, written down with regard to sign in succeeding columns.

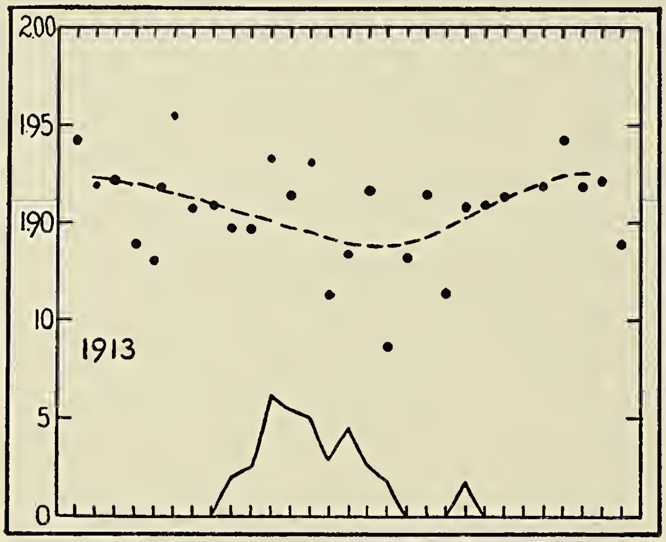


Fig. 19.—Twenty-five day periodicity in observations of 1913.

Now it is apparent that if after 10 days, for instance, the solar constant tends to repeat itself, or in other words, if there is a 10-day period, then the average differences at the 10-day column will be less than those for columns where no periodicity occurs. In view, however, of the evanescent quality of such periodicities, as just remarked, we thought it best not to take the year as a whole, but divided it into five intervals extending as follows:

I.	II.	III.	IV.	V.
July 1–Sept. 13, 1919.	Sept. 14–Nov. 17, 1919.	Nov. 18, 1919–Jan. 31, 1920.	Feb. 1–Apr. 15, 1920.	Apr. 16–June 27, 1920.

Each interval included more than two and a half solar rotations. We were in doubt whether to make an allowance for the long interval swings of the solar-constant value about the mean for the year. Accordingly the positive and negative departures were added separately. With few exceptions, however, the positive and negative sums agreed so nearly that it seemed not necessary to keep them distinguished longer, and so the mean departures without regard to sign are given in the following Table 60, and in figure 20.

The results of this study of Aldrich's are quite surprising. Though several of the groups, and indeed the general mean, give something of a diminution of the average departure at about 29 to 32 days, which corresponds fairly well with the solar-rotation period, this is not the principal feature of the curves. The rapid rise of the mean departures from the first to the ninth day, and the more rapid fall from the ninth to the thirteenth day, which is by all means the most conspicuous minimum of the curves, is quite extraordinary. Curiously enough, an almost exactly similar feature is shown in the temperature march of Buenos Aires for the years 1913, 1914, 1915, and 1918, as shown by the frontispiece to Clayton's paper reproduced as figure 12 of the present volume. We do not regard this as more than a coincidence, but feel that the data so far gained ought to be amplified in future publications before giving further conclusions as to the periodicity of solar variation. Up to the present we see no permanent periods established.

TABLE 60.—*Periodicities in solar variation.*

Days after.	Mean departures of solar constant (calories).					
	Group I.	Group II.	Group III.	Group IV.	Group V.	General mean.
1	0.0148	0.0140	0.0187	0.0141	0.0158	0.0155
2	.0171	.0139	.0181	.0184	.0156	.0166
3	.0166	.0150	.0191	.0220	.0139	.0172
4	.0168	.0162	.0179	.0218	.0144	.0174
5	.0171	.0120	.0193	.0213	.0149	.0170
6	.0168	.0135	.0219	.0214	.0149	.0177
7	.0184	.0137	.0210	.0222	.0147	.0181
8	.0198	.0160	.0222	.0225	.0146	.0190
9	.0197	.0160	.0228	.0235	.0143	.0193
10	.0188	.0135	.0222	.0239	.0170	.0192
11	.0177	.0157	.0222	.0203	.0147	.0180
12	.0182	.0156	.0211	.0220	.0138	.0181
13	.0177	.0149	.0132	.0180	.0155	.0160
14	.0163	.0167	.0196	.0184	.0144	.0170
15	.0162	.0134	.0229	.0185	.0153	.0172
16	.0189	.0179	.0210	.0187	.0157	.0184
17	.0170	.0157	.0199	.0211	.0115	.0171
18	.0176	.0144	.0237	.0212	.0150	.0184
19	.0173	.0160	.0228	.0196	.0154	.0182
20	.0154	.0143	.0209	.0198	.0157	.0173
21	.0153	.0154	.0246	.0218	.0153	.0185
22	.0173	.0173	.0211	.0236	.0168	.0193
23	.0195	.0165	.0220	.0216	.0134	.0186
24	.0155	.0171	.0185	.0218	.0170	.0180
25	.0172	.0173	.0204	.0227	.0172	.0190
26	.0180	.0192	.0218	.0228	.0152	.0194
27	.0182	.0184	.0249	.0222	.0176	.0203
28	.0176	.0187	.0229	.0218	.0160	.0194
29	.0174	.0184	.0260	.0190	.0164	.0192
30	.0187	.0172	.0222	.0197	.0146	.0184
31	.0193	.0193	.0240	.0194	.0151	.0193
32	.0185	.0173	.0228	.0189	.0146	.0183
33	.0197	.0192	.0229	.0184	.0169	.0193
34	.0171	.0192	.0282	.0197	.0156	.0198
35	.0174	.0174	.0243	.0204	.0154	.0190

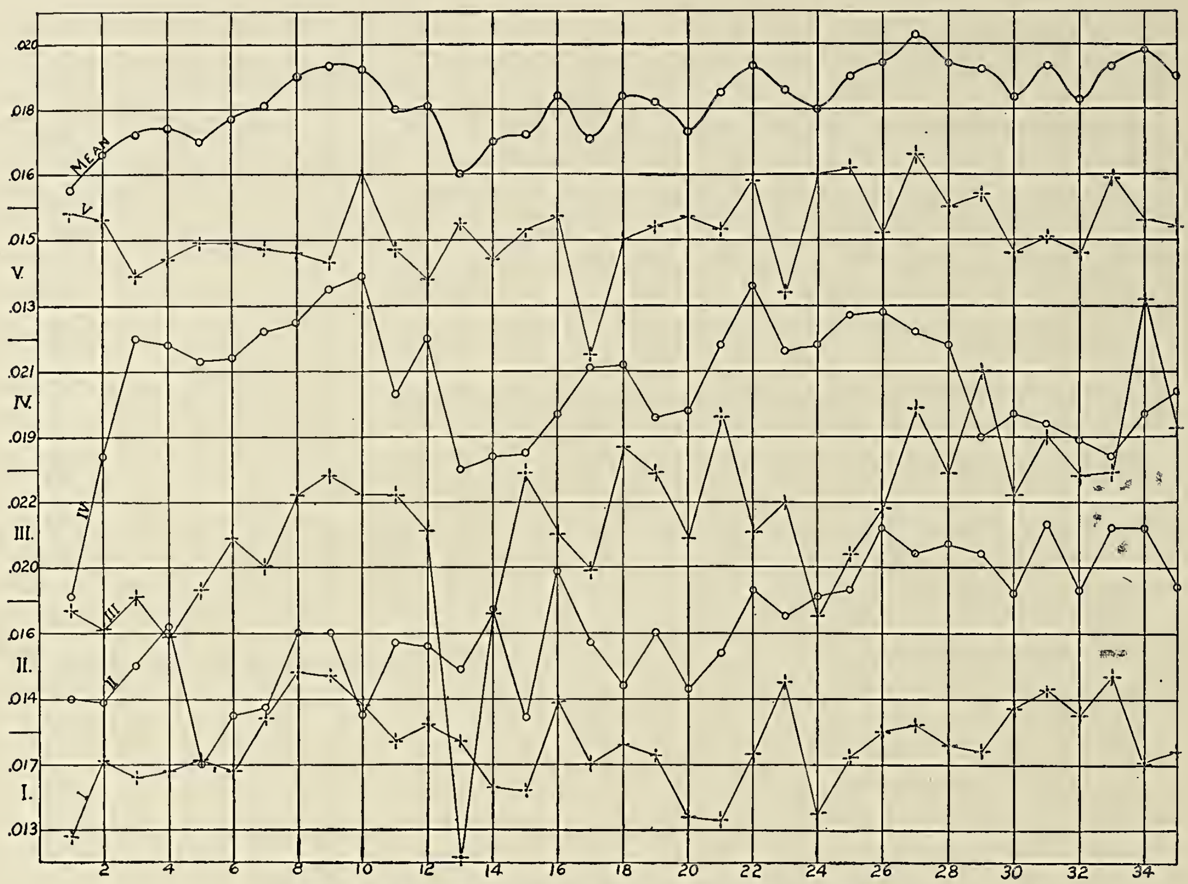


Fig. 20.—Periodicities in the solar constant. Calama observations, 1919–1920.

VII. SUN SPOTS AND THE SOLAR VARIATION.

As stated at page 129 of Volume III of the Annals, the earlier work on the intensity of the solar radiation seemed to indicate a connection between the values of the solar constant and the prevalence of sun spots. The connection, however, was not very close and it was stated that it would be well to reserve a decision on the point as to the correlation of the solar constant of radiation with sun spots until the passage of a few more years should have yielded observations which would be decisive.

We now give the results along this line which have become available since the year 1912. Instead of giving monthly means of sun-spot numbers and corresponding solar-constant values, as in Volume III, we have thought it preferable to collect the observations of all the years in groups, depending on the prevailing daily sun-spot numbers. Thus, for instance, in the year 1914, when the sun-spot numbers published by Wolfer ranged between 1 and 20, there were found 29 days of solar-constant observations averaging 1.956, and between the sun-spot numbers 20 and 30 there were 9 solar-constant values averaging 1.944. In this manner we present all the available Mount Wilson data of 1913 to 1920 in the following Table 61.

For the years 1915 to 1919, inclusive, there is a wide range of solar-constant and sun-spot data available, and we present these results graphically in figure 21, together with the general mean results for all years, 1913 to 1920. In some cases where the numbers of observations were very small, we have combined two or even three groups from Table 61 in the figure.

TABLE 61.—*Mount Wilson solar-constant values and the sun-spot numbers.*

Sun spots	0		1–20		20–30		30–40		40–50		50–60		60–70		70–80	
Year.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.
1913	67	1. 909	11	1. 886												
1914	40	1. 959	29	1. 956	9	1. 944	6	1. 946								
1915			7	1. 941	9	1. 960	10	1. 950	17	1. 964	11	1. 953	11	1. 958	10	1. 945
1916			11	1. 936	14	1. 943	8	1. 927	11	1. 943	10	1. 920	7	1. 934	5	1. 946
1917											3	1. 959	4	1. 944	6	1. 946
1918							5	1. 932	3	1. 962			9	1. 960	6	1. 949
1919					4	1. 955	7	1. 948	9	1. 954	14	1. 945	4	1. 946	7	1. 941
1920			11	1. 919	15	1. 954	8	1. 944	7	1. 919						
Means	110	1. 928	70	1. 933	51	1. 950	44	1. 942	51	1. 950	39	1. 943	35	1. 951	34	1. 948

Sun spots	80–90		90–100		100–110		110–120		120–130		130–140		140–150		200–250	
Year.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.	Number of items.	Solar-constant values.
1913																
1914																
1915	7	1. 943	6	1. 948	4	1. 956	6	1. 930					4	1. 959		
1916	3	1. 994					4	1. 958	3	1. 965						
1917	7	1. 975	5	1. 952	7	1. 975	4	2. 002	3	1. 939			5	1. 979	6	1. 960
1918	3	1. 954	3	1. 941	5	1. 994	6	1. 943	8	1. 928	3	1. 968	4	1. 950		
1919			5	1. 938	5	1. 955										
1920																
Means	22	1. 963	21	1. 946	22	1. 970	22	1. 956	17	1. 938	7	1. 958	14	1. 963	6	1. 960

Although the plot for the general mean of all years seems to support rather definitely the view suggested by the discussion contained in these Annals, Volume III, namely, that increasing sun-spot numbers are associated with increasing solar-constant values, yet some of the individual years show neutral or contradictory results, notably 1915 and 1919.

We are not surprised at this. We have drawn attention already to the considerable fall in solar-constant values which attended the central passage of the great sun-spot group of March 20, 1920. Thus it appears that although sun spots may betoken increased solar activity and attend on that account higher solar-radiation values, yet locally on the sun they may be associated with interferences

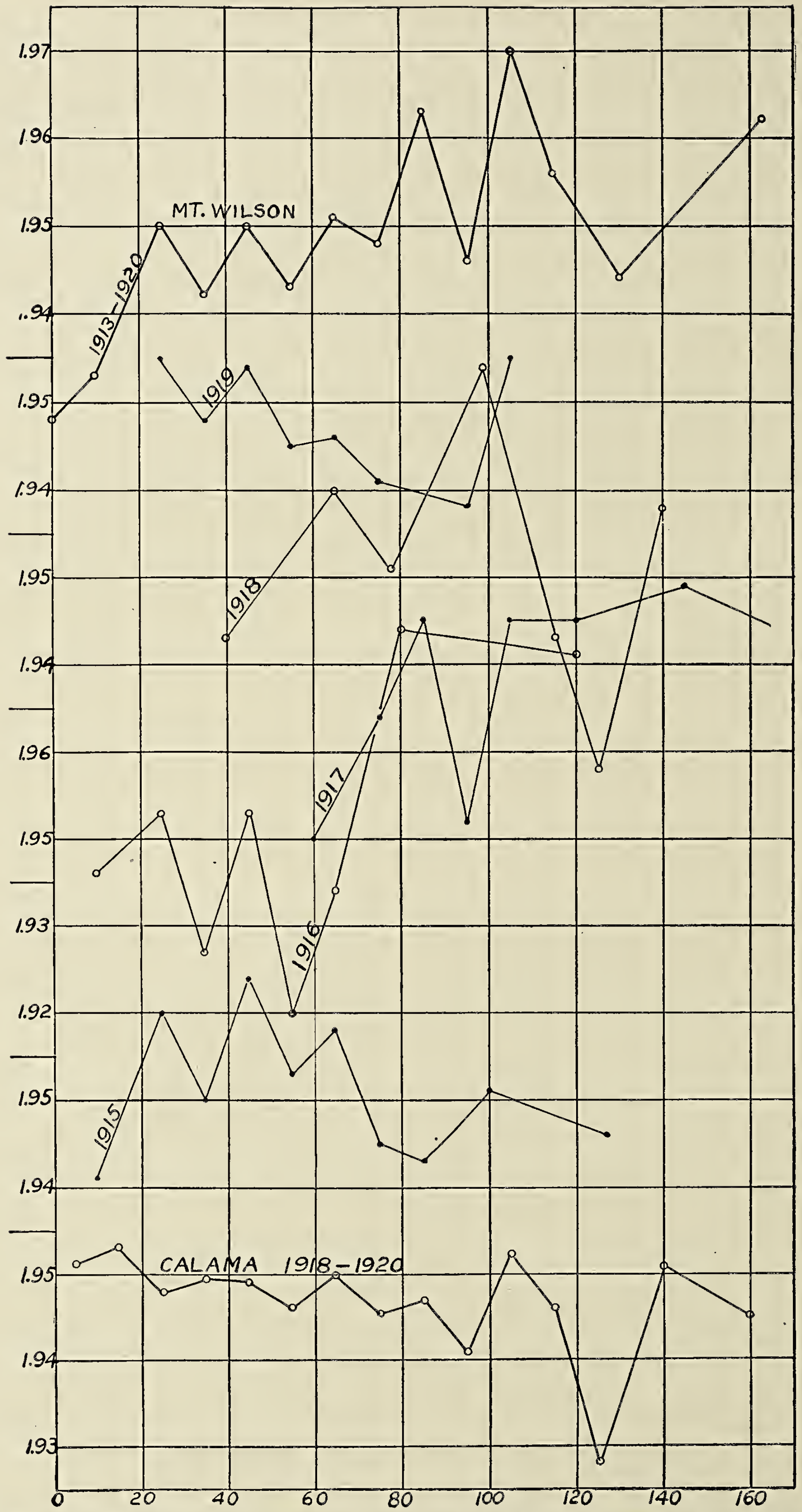


FIG. 21.—The solar-constant and sun-spot numbers. Ordinates, solar constant values. Abscissae, Wolf sun-spot numbers.

to the output of solar rays in particular directions. Such interfering elements may often obscure the path of rays toward the earth, and so produce frequently large depressions of observed solar radiation at times of high sun-spot numbers.

It is not therefore surprising that in the general sun-spot and solar-radiation curve the year 1915, for example, takes its expected place, high in sun spots and high in solar radiation. But taking 1915 alone, the march of the two variables for individual days is fluctuating, tending sometimes toward positive, at other times toward negative correlations.

It might be worth while to go more minutely into the study of the correlation between sun spots and solar-constant values. It is not unlikely that if the positions on the solar disk of the sun-spot groups were considered, as well as their number and magnitude, closer correspondences would appear. We have not attempted this, partly from lack of time to devote to it, and partly because of the insufficiency and frequently poor quality of the Mount Wilson solar-constant values. Such a study could doubtless lead to better results if undertaken after several years of the check observations of Montezuma and Harqua Hala have become available.

We have made one further trial of the relations of sun spots to solar-constant values, employing the results of the period July, 1918, to July, 1920, inclusive, at Calama. These solar-constant values, we believe, are the most accurate as well as the most continuous available. In the following table is a summary of these results giving, between certain limits of sun-spot numbers, the mean solar-constant values and their numbers. In figure 21 the data are given graphically. The tendency is slight but unmistakable toward decreasing solar radiation with increasing sun-spot numbers.

TABLE 62.—*Sun-spots and solar-constant values, Calama, 1918–1920.*

Sun-spot numbers....	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100	100–110	110–120	120–130	130–150	>150
Mean solar constant....	1.9512	1.9531	1.9481	1.9498	1.9491	1.9461	1.9499	1.9453	1.9468	1.9408	1.9524	1.9460	1.9282	1.9509	1.9451
Number of observations...	17	40	61	65	73	62	65	49	29	25	23	26	13	17	9

Dr. Bauer has recently presented evidence on the correlation between the monthly fluctuations of both sun-spot numbers and solar-constant values.

Dr. Ångström [10] finds the Mount Wilson values of 1915–1917 fairly represented by the formula

$$S=1.903+0.011\sqrt{N}-0.0006N$$

where S is the solar constant and N the Wolf-Wolfer sun-spot number.

Our investigations lead us to fear that no single formula will be found capable of expressing the relations of sun spots to solar constants for more than a brief period.

[10] Astrophysical Journal, September, 1921.

Chapter VII.

ON THE DISTRIBUTION OF RADIATION OVER THE SUN'S DISK.

In earlier volumes of the Annals we have described the methods then in use for examining the distribution of the solar radiation in different wave lengths along the east and west diameter of the sun. In our paper on this subject,[1] "On the Distribution of Radiation over the Sun's Disk and New Evidences of the Solar Variation," we gave the results which had been reached in 1913 and 1914 at Mount Wilson, as compared with those which were reached at Washington in the year 1907. As it describes in detail the methods which were followed at Mount Wilson from 1913 to 1920 almost unchanged, and includes the basic observations of 1913, with which all subsequent work has been compared, we reprint the above cited paper complete at this point, excepting table 9, table 10, figure 7, the Summary, and the Appendix, all of which are either contained below in better form or relate to extraneous matters.

DISTRIBUTION EXPERIMENTS 1907 TO 1914.

Referring to the Annals of the Astrophysical Observatory,[2] we gave there the results of earlier investigations of the distribution of radiation over the sun's disk, and some indications of a variability of this distribution which might be associated with variation of the sun's total radiation. This work was done in Washington prior to the year 1908. When the new observing station of the Smithsonian Institution was constructed upon Mount Wilson in 1909, provision was made for the erection of a tower to be used for a tower telescope for the continuation of such observations. It proved impossible to equip a tower telescope until the autumn of the year 1913, when apparatus was hastily arranged and operations were begun on September 9, 1913. The tower was improved both in its rigidity and in the mountings of the apparatus for the research in 1914 and 1915, and is now regularly used on all days when solar-constant observations are made.

In figure 22 is given a general view of the tower telescope upon the observing station at Mount Wilson. Owing to the bold situation of the station, it is impossible to get a photograph of the apparatus except by climbing a tall pine tree at some distance away, and the trees intervening are some obstacle to a satisfactory presentation of the installation.

Figure 24 is a diagram of the construction of the tower telescope and its relation to the spectrobolometer. *A* and *B* are the mirrors of the coelostat, from which a beam of sunlight passes downward to the 30-centimeter (12-inch) concave mirror *C* of 23 meters (75 feet) focal length. Thence the beam passes up to the plane mirror *D*, which reflects the image to focus at *E* near the floor of the observing chamber. At *F* is a small plane mirror at the angle of 45°, which reflects the beam through the slit *G* of the spectrobolometer *G H I*. At *J K*, outside the observing chamber, is the coelostat used for the ordinary solar-constant observations.

The reader will understand that the beam from the coelostat *A B*, or that from the coelostat *J K*, may be brought to the spectrobolometer, according as the 45° mirror *F* is in place or withdrawn. The former is the condition for observing the distribution of light over the sun's disk, the latter the condition for observing the solar constant of radiation.

As explained in the publications already cited, we allow the sun's image to drift across the slit of the spectrobolometer by the diurnal motion of the earth, thus avoiding all sources

[1] Smithsonian Miscellaneous Collections, vol. 66, no. 5.

[2] Vol. II, pt. 3, and vol. III, ch. 7.

of error associated with inequalities of the transmission of the optical apparatus of the tower telescope. For it is obvious that during a single such period of drift the telescope is always directed to the same point of the sky, and treats whatever object passes that point with impartiality, whether it be the sun's limb, center, or the light of the sky itself. We regard this feature as very favorable for exact results, and much preferable to the arrangement used by some investigators, in which the observing apparatus is shifted about from part to part of the solar image, and the results may be affected by inequalities of transmission of the optical apparatus to these different parts of the image.

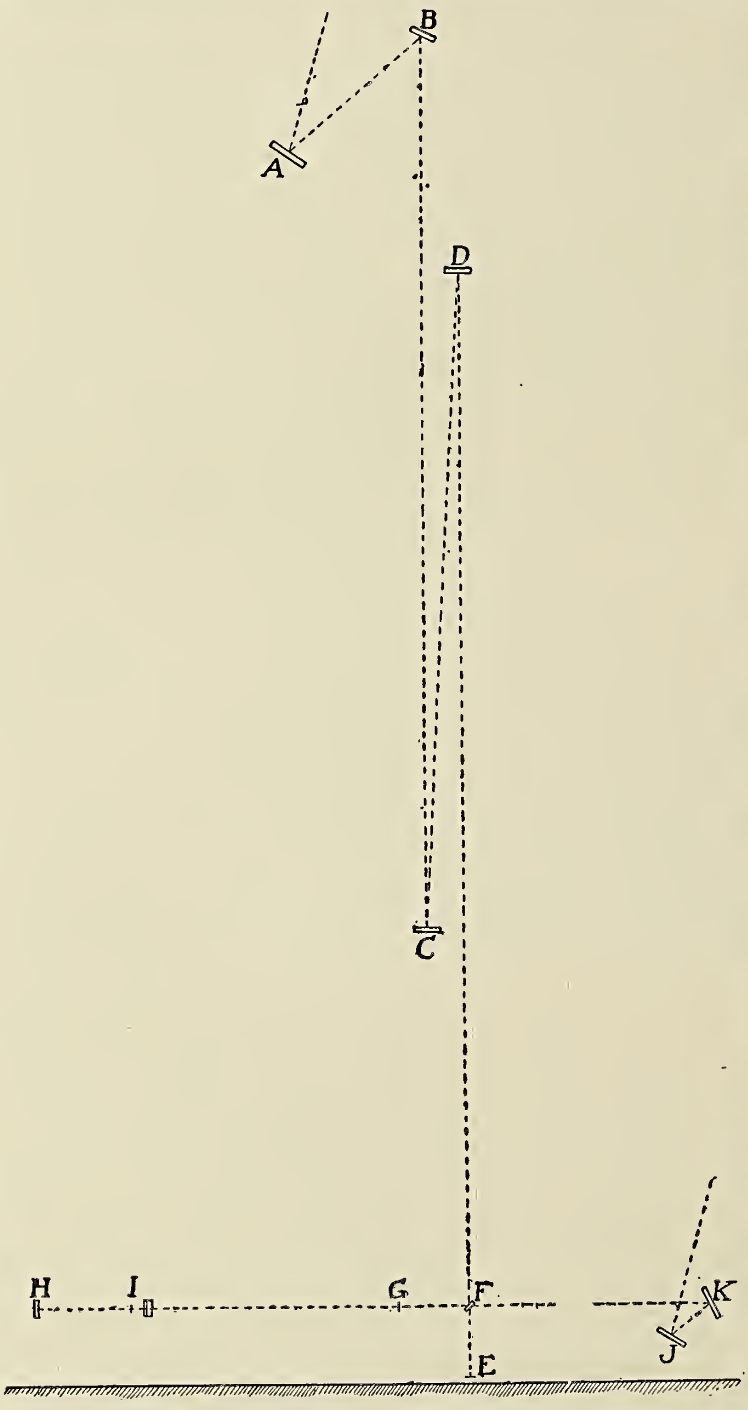


FIG. 24.—Diagram of tower telescope and spectrobolometer.

On the other hand, we are thereby limited to an east and west course across the sun's disk, and this hardly ever coincides with the solar equator. However, it seems clear that a comparison of the mean of a great number of observations taken during a large part of one year with that of a great number of similar observations covering the same part of another year, would certainly be fairly comparable irrespective of the various presentations of the sun during these intervals. It is by no means so clear, without further investigations which we hope to undertake next year, that short-period changes of the distribution of radiation along a solar diameter may not be associated with changes of distribution depending on latitude in the sun. Such investigations as have been made on this point heretofore relate, we think, only to total brightness or total radiation. Pickering's[3] experiments indicated that the contrast of visual brightness along a polar diameter exceeds that along the equatorial, so that for total visual brightness at 95 per cent out on the radius the equator is brighter in the ratio of about 56 to 53. Pickering expressed doubt as to whether this difference is solar or from experimental error. The more numerous investigations of Langley[4] seem to have shown

[3] Proceedings American Academy of Arts and Sciences, vol. 10, p. 428, 1874. [4] Comptes Rendus, Sept. 6, 1875.

FIG. 22.—MOUNT WILSON TOWER TELESCOPE.

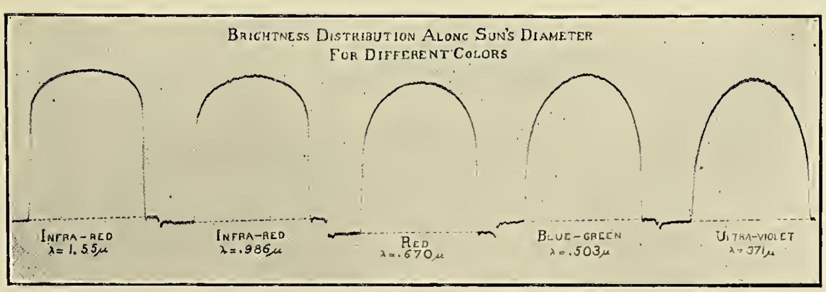


FIG. 23.—BRIGHTNESS DISTRIBUTION ALONG SOLAR DIAMETER FOR DIFFERENT COLORS.

clearly that differences of contrast in total radiation between the equatorial and polar diameters of the sun are negligibly small, probably far less than 1 per cent. Hence it seems probable that the influence of changes in the inclination of the solar equator as affecting our investigations is inappreciable.

Figure 23 shows a number of drift curves at selected regions of the spectrum chosen to indicate the differences of form which are found, depending on wave lengths. As discovered by earlier investigators, and hitherto abundantly confirmed by ourselves, the contrast of brightness between the center and the edge of the sun is greatest for short wave lengths, and diminishes as one comes to the red and infra-red.

We have two principal objects in this research: First, to repeat our earlier determination of the distribution of light along the diameter of the solar image; second, to detect fluctuations of distribution from year to year and from day to day, if any, and to compare them, if found, with fluctuations of the radiation of the sun as determined in our solar-constant investigations.

On each day of observation we are accustomed to take 14 drift curves, two each at seven different wave lengths, as follows: 0.3737μ, 0.4265μ, 0.5062μ, 0.5955μ, 0.6702μ, 0.8580μ, and 1.008μ. In the reduction of observations, we proceed as stated on pages 154 and 155 of volume III of our Annals, from which we quote as follows:

"We have determined the rate of descent in the plate carrier of the photographic plates on which the curves are recorded, and have determined from the Nautical Almanac the time required for the sun's disk to pass the meridian. From these data we have determined the distance along the plate corresponding to the width of the sun's diameter. This distance has been regarded as the true width of the U-shaped curve, and all the measurements of ordinates of this curve have been made at certain round-numbered fractions of the corresponding solar radius.

"To illustrate: On June 8, 1908, the sidereal time required for the sun's semidiameter to pass the meridian was 1^{m} 8.72^{s}. The corresponding mean solar time for the passage of the diameter is 2.284^{m}. On this date the photographic plate descended 3.978 centimeters per minute. Hence, the diameter of the sun expressed on the photographic plate is 9.086 centimeters. Measurements were made at the center and at 10 places on either side of it, making 21 places in all, at distances from the center of the U-shaped curve which correspond to certain fractions of the solar radius from the center of the sun's disk.

"In further reduction of the observations, the mean values of the measurements on each curve for the advancing and following limbs of the sun were taken. Then, in order to standardize the observations (for it is to be remembered that the bolographic curves depend for their ordinates on the sensitiveness of the galvanometer, the clearness of the sky, and the sun's zenith distance, all of which vary from day to day), the sums of the mean measurements at the center (given half weight) and at 2/10, 4/10, 55/100, and 65/100 radius, were taken. All the measurements were divided by this sum and thus expressed in terms of a unit five times the mean height of the central part of the U-shaped curve.

"For illustration: On June 8, 1908, the following measurements were made on a curve corresponding to wave length 0.501μ. Taking the sum, 40.96, of the first five places (giving the central place half-weight) and dividing this sum into the mean values at the several places on the curve, we have the following values:

TABLE 63.—*Illustrative of reduction of drift curve observations.*

Distances from center:	*cm.*										
Linear	0.00	0.91	1.82	2.50	2.95	3.41	3.75	3.98	4.18	4.32	4.41
Fractional	0.00	0.20	0.40	0.55	0.65	0.75	0.825	0.875	0.92	0.95	0.97
Heights:											
Advancing limb	9.80	9.69	9.16	8.74	8.41	7.61	6.96	6.35	5.65	4.70	3.60
Following limb	....	9.69	9.26	8.81	8.36	7.68	7.03	6.37	5.58	4.78	4.16
Mean	2×4.90	9.69	9.21	8.775	8.385	7.645	6.995	6.36	5.615	4.74	3.88
Ratio, mean height to 40.96.	.1196	.2366	.2249	.2142	.2047	.1866	.1708	.1553	.1371	.1157	.0947
Ratio to central height [1]	1.0000	.9862	.9379	.8932	.8536	.7781	.7123	.6476	.5717	.4825	.3949

[1] The lowest line of the table is added in view of its interest, but is not used in the reductions. It is based on the standard central value 0.1199 found from 104 curves. It will be further explained.

AUXILIARY STANDARD REDUCTION VALUES.

"The following table contains the standard reduction values for many wave lengths. It corresponds to the next to the last line of table above, represents the mean of many days of observation, and is used in preparation of the tables which follow it.

Table 64.—*Mean distribution of radiation along radius of solar disk.*

Wave length.	Number of observations.	Distance from center as fraction of radius.									
		0.00[1]	0.20	0.40	0.55	0.65	0.75	0.825	0.875	0.92	0.95
μ											
0.386	3	0.1233	0.2417	0.2283	0.2110	0.1953	0.1750	0.1560	0.1367	0.1190	0.1030
0.433	39	.1227	.2400	.2275	.2126	.1978	.1789	.1588	.1430	.1251	.1104
0.456	89	.1207	.2380	.2273	.2136	.2007	.1826	.1644	.1487	.1298	.1136
0.481	74	.1201	.2371	.2267	.2141	.2018	.1851	.1683	.1532	.1359	.1198
0.501	104	.1199	.2362	.2267	.2145	.2026	.1864	.1704	.1559	.1397	.1240
0.534	104	.1192	.2353	.2265	.2150	.2041	.1888	.1736	.1602	.1443	.1306
0.604	72	.1182	.2339	.2262	.2158	.2062	.1929	.1798	.1679	.1533	.1403
0.670	41	.1173	.2324	.2255	.2168	.2081	.1965	.1844	.1737	.1596	.1476
0.699	64	.1171	.2319	.2255	.2169	.2085	.1970	.1856	.1751	.1618	.1492
0.866	51	.1160	.2302	.2248	.2178	.2113	.2021	.1926	.1837	.1726	.1621
1.031	30	.1149	.2293	.2246	.2185	.2126	.2042	.1955	.1875	.1775	.1677
1.225	43	.1148	.2284	.2240	.2188	.2139	.2068	.1987	.1914	.1824	.1737
1.655	26	.1138	.2268	.2236	.2198	.2163	.2111	.2051	.1996	.1928	.1856
2.097	25	.1134	.2260	.2236	.2202	.2169	.2123	.2075	.2024	.1965	.1900

On half the scale of other columns.

"The values in the table just given are a standard of reference, and the values obtained at these wave lengths on any day of observation are comparable with them as soon as reduced to the form given in the next to the last line of Table 63.

MEAN DISTRIBUTION OF RADIATION ALONG THE SOLAR RADIUS FOR DIFFERENT WAVE LENGTHS.

"The following tabular summary of the distribution of brightness of different wave lengths along the diameter of the sun's disk has been obtained in the manner just described from numerous observations made between November 1, 1906, and January 1, 1908. Profs. Schwartzchild and Villager determined the distribution of radiation along the diameter of the sun for the very short wave length, $\lambda = 0.323\mu$, by photographic observations made after silvering the objective of their telescope.[5] In this way they observed only with the ultra-violet rays transmissible by silver. The following table includes the mean of observations of Schwartzchild and Villager:

Table 65.—*Mean distribution of radiation along radius of solar disk.*

[Intensity at center as unit.]

Wave length.	Number of observations.	Distance from center as fraction of radius.									
		0.00	0.20	0.40	0.55	0.65	0.75	0.825	0.875	0.92	0.95
μ											
0.323	....	1.0000	0.960	0.897	0.835	0.775	0.690	0.600	0.530	0.452	0.382
0.386	3	1.0000	.9797	.9258	.8556	.7920	.7097	.6326	.5543	.4826	.4177
0.433	39	1.0000	.9780	.9271	.8663	.8060	.7290	.6471	.5827	.5098	.4499
0.456	89	1.0000	.9857	.9416	.8848	.8314	.7564	.6810	.6160	.5377	.4706
0.481	74	1.0000	.9871	.9438	.8914	.8401	.7706	.7007	.6378	.5658	.4988
0.501	104	1.0000	.9850	.9454	.8945	.8449	.7773	.7106	.6501	.5826	.5171
0.534	104	1.0000	.9870	.9499	.9018	.8561	.7919	.7282	.6720	.6053	.5478
0.604	72	1.0000	.9894	.9568	.9129	.8722	.8160	.7606	.7102	.6485	.5935
0.670	41	1.0000	.9906	.9612	.9241	.8769	.8376	.7860	.7404	.6803	.6292
0.699	64	1.0000	.9902	.9629	.9261	.8903	.8412	.7925	.7476	.6909	.6371
0.866	51	1.0000	.9922	.9690	.9388	.9108	.8711	.8302	.7918	.7440	.6987
1.031	30	1.0000	.9978	.9774	.9508	.9251	.8886	.8507	.8159	.7904	.7298
1.225	43	1.0000	.9948	.9779	.9530	.9316	.9007	.8654	.8336	.7944	.7565
1.655	26	1.0000	.9965	.9820	.9657	.9504	.9275	.9012	.8770	.8471	.8155
2.097	25	1.0000	.9965	.9858	.9709	.9563	.9361	.9149	.8924	.8664	.8374

[5] Astrophysical Journal, vol. 23, pp. 284 to 305, 1906.

We now give the mean distribution of radiation along the solar radius for different wave lengths as found by the observations of 1913. The tables here given are conformable to Tables 54 and 55 of volume III of the Annals. They relate, however, to other wave lengths.

Table 66.—*Auxiliary standard reduction values of 1913.*

Wave length.	Number of observations.	Distance from center as fraction of radius.										
		0.00	0.20	0.40	0.55	0.65	0.75	0.825	0.875	0.92	0.95	0.97
μ												
0.3737	84	0.1219	0.2401	0.2278	0.2123	0.1978	0.1781	0.1589	0.1413	0.1217	0.1053	0.0852
0.4265	81	.1218	.2399	.2282	.2124	.1978	.1787	.1595	.1431	.1245	.1084	.0946
0.5062	87	.1193	.2360	.2269	.2147	.2032	.1878	.1717	.1576	.1410	.1262	.1126
0.5955	82	.1179	.2335	.2261	.2161	.2065	.1935	.1802	.1681	.1536	.1402	.1276
0.6702	83	.1168	.2319	.2258	.2170	.2086	.1972	.1856	.1747	.1617	.1495	....
0.8580	82	.1156	.2297	.2247	.2182	.2118	.2027	.1932	.1847	.1741	.1642	....
1.0080	78	.1152	.2290	.2246	.2186	.2126	.2046	.1960	.1881	.1781	.1689	....

Table 67.—*Standard distribution of radiation along radius of solar disk, 1913.*

Wave length.	Number of observations.	Distance from center as fraction of radius.										
		0.00	0.20	0.40	0.55	0.65	0.75	0.825	0.875	0.92	0.95	0.97
μ												
0.3737	84	1.0000	0.9841	0.9344	0.8708	0.8113	0.7305	0.6518	0.5796	0.4992	0.4319	0.3495
0.4265	81	1.0000	.9848	.9368	.8719	.8120	.7336	.6548	.5874	.5111	.4450	.3883
0.5062	87	1.0000	.9891	.9510	.8998	.8516	.7871	.7196	.6605	.5909	.5289	.4719
0.5955	82	1.0000	.9902	.9589	.9165	.8757	.8206	.7642	.7129	.6514	.5946	.5411
0.6702	83	1.0000	.9927	.9666	.9289	.8930	.8442	.7945	.7479	.6922	.6400	....
0.8580	82	1.0000	.9935	.9719	.9438	.9161	.8767	.8356	.7989	.7530	.7102	....
1.0080	78	1.0000	.9939	.9748	.9488	.9227	.8880	.8507	.8164	.7730	.7331	....

CHANGES OF DISTRIBUTION FROM YEAR TO YEAR.

We have compared the distribution for 1907 with that for 1913. It was at once apparent that a change of distribution had occurred. Inasmuch as the year 1913 was a year of absolute minimum of sun spots such as has not been equaled for almost a century, it seemed well to use the distribution obtained in 1913 as a standard of reference.

Imagine tables to be formed for other years, similar to that which we have just given for 1913. Imagine, further, that we divide each number of the table for another year by the corresponding number of the table for 1913. There results, for each wave length, a series of values. Having adjusted the values so that smooth curves to represent them would give zero departures at the center of the sun's disk, the actual values, starting near unity at the center of the sun's disk, run to numbers slightly smaller or larger than unity as we approach the edge of the disk, according as the distribution in the given year shows a greater or a less contrast of brightness between the center and the edge than that which prevailed in the standard year 1913.

In the following Table 68 are given the results of such comparisons for the years 1907 and 1914. It was necessary to reduce the observations of 1907 to the wave lengths employed in 1913 and 1914. This was accomplished by plotting the tabular values on a very large scale and interpolating for the proper wave length. The 67 observations of 1914 which are here represented were obtained between June 12 and October 5. Other observations of 1914 are not as yet reduced.

TABLE 68.—*Comparison of distribution values of other years with results of 1913.*

Year.	Wave length.	Distance from center as fraction of radius.									
		0.00	0.20	0.40	0.55	0.65	0.75	0.825	0.875	0.92	0.95
	μ										
1907	0.4265	1.0033	0.9996	0.9966	0.9992	0.9992	0.9981	0.9967	0.9929	0.9903	0.9918
1907	0.5062	1.0017	.9991	.9970	.9978	.9968	.9930	.9936	.9920	.9926	.9888
1907	0.5955	1.0005	.9997	.9976	.9971	.9956	.9928	.9919	.9915	.9902	.9909
1907	0.6702	1.0018	.9989	.9958	.9953	.9938	.9916	.9892	.9898	.9837	.9840
1907	0.8580	1.0000	1.0000	.9978	.9956	.9946	.9930	.9922	.9904	.9865	.9809
1907	1.0080	.9986	1.0012	.9991	.9986	.9990	.9966	.9962	.9936	.9933	.9906
	Mean ..	1.0010	0.9997	0.9973	0.9973	0.9965	0.9942	0.9950	0.9934	0.9894	0.9878
1914	0.3737	1.0005	0.9990	0.9983	0.9977	0.9963	0.9957	0.9939	0.9955	0.9943	0.9926
1914	0.4265	.9998	1.0002	.9987	.9985	.9983	.9973	.9962	.9966	.9946	.9939
1914	0.5062	1.0002	.9996	.9994	.9990	.9984	.9973	.9972	.9976	.9964	.9956
1914	0.5955	1.0000	1.0000	.9997	.9995	.9992	.9987	.9978	.9977	.9966	.9975
1914	0.6702	1.0006	.9999	.9991	.9988	.9985	.9977	.9966	.9968	.9961	.9970
1914	0.8580	.9996	.9998	.9999	.9989	.9983	.9985	.9981	.9979	.9975	.9990
1914	1.0080	.9997	1.0000	.9999	.9996	.9997	.9992	.9990	.9991	.9992	1.0008
	Mean ..	1.0001	0.9998	0.9993	0.9988	0.9984	0.9978	0.9970	0.9975	0.9964	0.9966

The results just given are indicated graphically in figure 25. Ordinates are ratios of the mean ordinates of drift curves for 1907 and 1914 compared to those of 1913 taken as standards. Abscissæ are positions along the solar radius, starting from zero at the center of the disk and running to 1.000 at the limb.

It appears that greater contrast prevailed in the years 1907 and 1914 than that which prevailed at sun-spot minimum in 1913; because when all the curves are reduced to equality at the center of the solar disk, they indicate lower values at the limb in the years 1907 and 1914 than in 1913. The differences are exceedingly small, although so unmistakable. Thus the average departure at 92 per cent on the radius is but 1 per cent in 1907 and but 0.36 per cent in 1914.

We have considered whether these differences are due to experimental error, but three considerations seem to us to oppose this view. First, no significant change in the apparatus or methods of experiment occurred between 1913 and 1914. Second, the fluctuations of contrast from day to day are correlated with fluctuations of the solar constant from day to day, as will appear below from very numerous cases occurring in 1913 and 1914. This being so, it is reasonable to expect also a fluctuation of contrast from year to year, if the solar radiation fluctuates from year to year. Greater values of solar radiation prevailed in 1907 [6] and 1914 than those prevailing in 1913. Hence it is not surprising to find that the contrast of brightness was greater in both the years 1907 and 1914 than it was in the year 1913. Third, there seems to be a correlation of change of contrast with change of wave length. This relation does not appear clearly from the results of 1907, but figure 25 shows that these results are subject to large experimental error compared with the results of 1914. A slightly different weighting of two discordant points on each of the curves for wave lengths 0.4265, 0.5062, 0.6702, and 1.008 μ in the curves for 1907 would bring them all (excepting that at wave length 0.8580 μ) into harmony with the conclusions about to be stated. Confining attention to the more accurate observations of 1914, the change of contrast is greater for short wave lengths than for longer ones, in the proportions indicated by Table 69.

Figure 26 shows graphically the dependence of the 1914 departures of contrast on the wave length. The evidence of future years will be required to show whether the irregularities of the curves of figure 26 are accidental or solar, but of the reality of the increase of departures attending decrease of wave length there seems to be little question.

[6] This statement regarding 1907 is based on the dependence between solar-constant values and sun-spot numbers indicated by figure 16 of volume 3 of our Annals. Few solar-constant determinations were made in 1907.

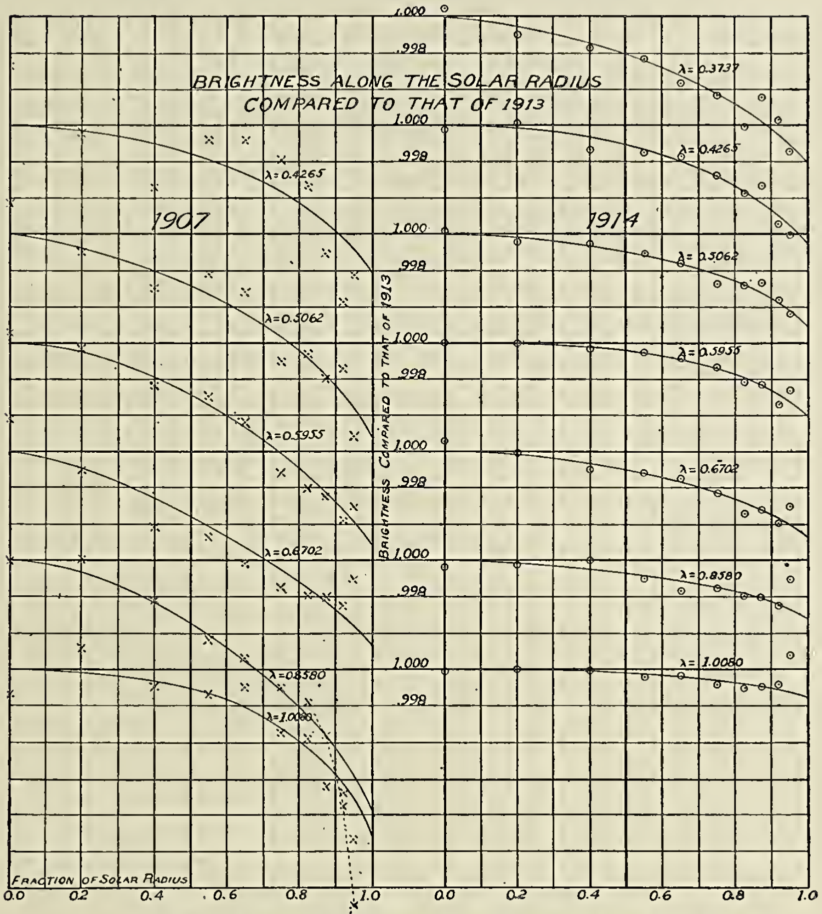


FIG. 25.—Variability of distribution of sun's brightness from year to year.

TABLE 69.—*Deviations of contrast of mean results of 1914 from standard form of 1913 (derived from mean curves).*

Wave length	μ 0.3737	μ 0.4265	μ 0.5062	μ 0.5955	μ 0.6702	μ 0.8580	μ 1.0080
Fraction of radius.							
0.50	0.0020	0.0010	0.0009	0.0004	0.0010	0.0007	0.0002
0.90	0.0062	0.0046	0.0035	0.0026	0.0035	0.0023	0.0010

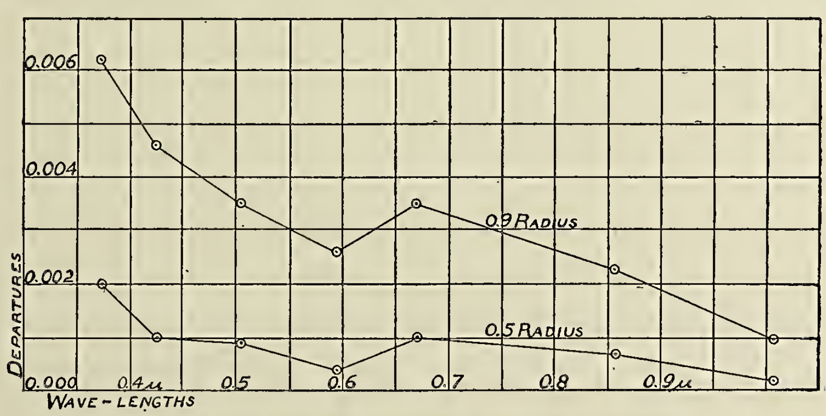


FIG 26.—Dependence of brightness variability on wave length.

CHANGES OF DISTRIBUTION FROM DAY TO DAY.

We now pass to a consideration of changes of contrast from day to day. Still using the mean distribution of 1913 as a standard, we took logarithms of the values and subtracted these from the corresponding logarithms for the individual days. We then plotted the resulting logarithms as ordinates, and the positions on the solar-disk radius as abscissæ. In this way we obtained for each day of observation seven plots, or pairs of plots, in which the slant of the representative lines indicated the departure from the standard mean condition of solar contrast, at seven different wave lengths. In the 1913 reductions we combined the pairs of check values before plotting, but kept them separate in the 1914 reductions.

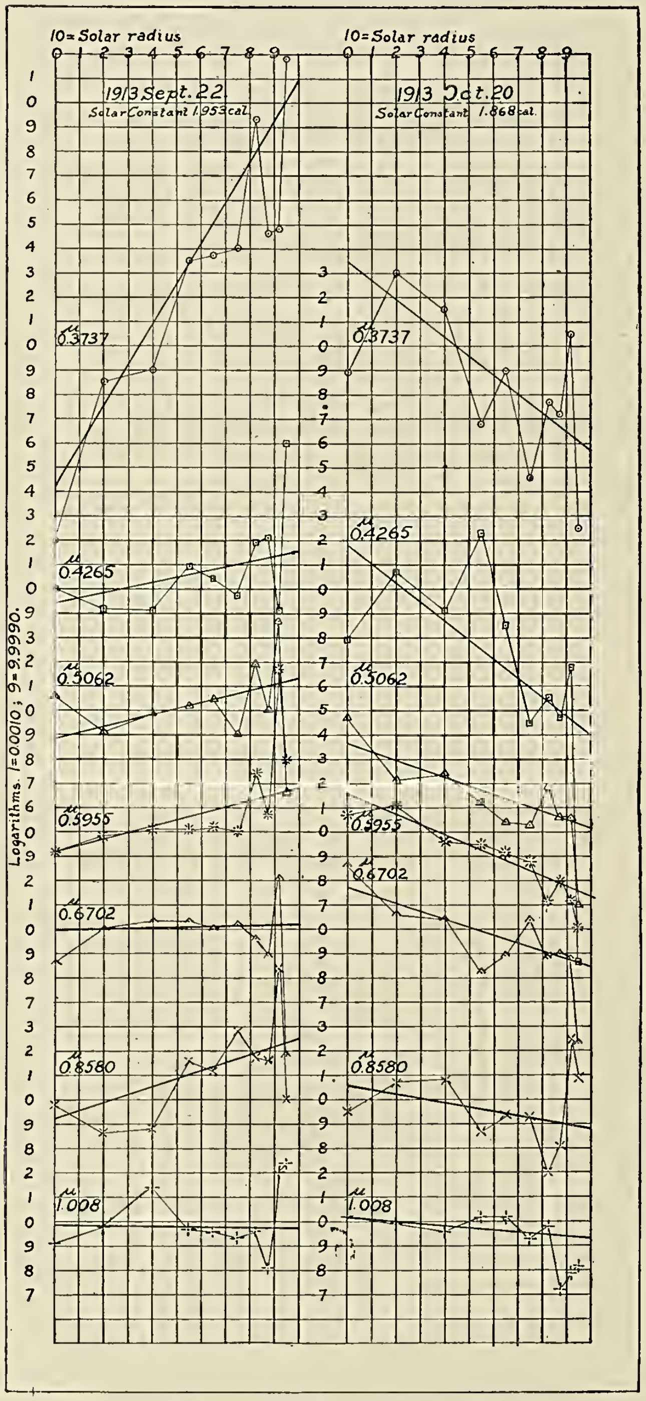


FIG. 27.—Variations of solar contrast from day to day.

Figure 27 shows the results of two days of comparison which are typical of the two different classes of results obtained on the various days. On September 22, 1913, the curves run generally upward, indicating a less contrast than the mean, while on October 20, 1913, the lines run generally downward, indicating a greater contrast than the mean. Some curves on each day, to be sure, run counter to the general trend of the day, but these divergences are reasonably to be regarded as often due to accidental error. A change of atmospheric transparency of 1 per cent during the single minute of time at which the central part of the sun's disk is crossing the slit of the spectroscope would account for the divergences shown by wave lengths 0.6702 and 1.008μ on September 22. Still more probably the discrepancy may be accounted for by a temporary shift of less than a millimeter in the zero of the bolometric curve either at the beginning, middle, or end of the runs.

We desired to obtain for each day's observation a single value which would be typical of each day's departure of contrast from the general mean. While logarithmic curves of departures are not always smooth, and while there is no physical reason on which to base a prediction of the form which they ought to assume, still in general the curves are tolerably represented by straight lines. We have regarded the inclination of the best representative line for each logarithmic plot as a fair indication of the departure of contrast for that day and that wave length. There are seven wave lengths observed on each day of observation, and we might have taken the simple mean value of the tangents of the inclination of the logarithmic lines as the index of the departure for the given day. But it appeared that the departures were greater, the smaller the wave lengths, so much so that the simple mean would give entirely too much weight to the shortest wave length of observation. Accordingly, a system of weights has been determined by comparing the magnitudes of the departures at the different wave lengths. The numbers for 1913 and 1914 were obtained independently from the data for those two years, and they differ somewhat from each other.[7] The weights for the two years were not smoothed by wave lengths. They are as follows:

TABLE 70.—*Adopted weights.*

Wave length, μ	0.3737	0.4265	0.5062	0.5955	0.6702	0.8580	1.0080
1913 values	0. 33	0. 79	1. 39	1. 00	1. 32	1. 47	2. 17
1914 values	0. 42	0. 59	0. 62	1. 00	0. 63	1. 00	1. 67

For the purpose in view, the differences between the two sets of weights are of little significance. The numbers are, on the whole, very like those which might be derived from figure 26.

We have made two different reductions of the data. In one, we multiplied the tangents for each day by the appropriate multiplier taken from the preceding table, and having taken the mean of the weighted tangents, we thus obtained for the given day a value representing the average weighted departure from the standard condition of distribution, as determined by observations at seven different wave lengths. In another reduction we omitted the wave lengths 0.3737 and 1.008 μ and took the simple mean of the tangents for the other wave lengths. We omitted these two wave lengths in consideration of the fact that the accidental error at 0.3737μ is unduly large, owing to the smallness of galvanometer deflections there; and also that the changes of contrast at wave length 1.008μ are relatively small compared with the accidental error there.

The following tables (75 and 76) give the solar-constant and solar-contrast numbers for the years 1913 and 1914.

As so much depends upon the values for 1913, a great deal of attention has been paid to the remarkable decrease of the solar-constant values which occurred on and after September 24, 1913. Not only did the solar-constant values fall off at this time, but also a change in the contrast values occurred. If we divide all the days in which solar-contrast values were obtained in 1913 into two groups, prior to and succeeding September 23, respectively, we find as follows:

TABLE 71.—*Comparison of results before and after Sept. 23, 1913.*

Observation period.	Solar-constant numbers.		Solar-contrast numbers.	
	Above 1.895 calories.	Below 1.895 calories.	Positive.	Negative.
Sept. 9 to Sept. 22	11	0	10	1
Sept. 24 to Nov. 9	8	24	15	17

Not only was this date critical with regard to solar-contrast and solar-constant values, but a marked change in the distribution and total amount of the water vapor in the atmosphere took place. The values of precipitable water in the atmosphere determined by Fowle's method were far above the normal until September 23, and from then to the end of the period of observation generally about normal or a little below. A similar change is indicated, but not in so great a degree, by the observations with the wet and dry thermometers. The temperature also fell at the same critical time. These changes are shown by Table 72.

[7] It may be significant in view of what follows to note that the weights obtained for 1913 depended on the relative amounts of the deviations of individual wave lengths on different days, while the weights obtained for 1914 depended rather on the relative deviations for these wave lengths found from the year as a whole, compared to 1913 as a whole.

TABLE 72.—*Mean Mount Wilson precipitable water, pressure of aqueous vapor, and dry bulb temperatures during observing periods.*

Observation period.	Precipitable water.	Pressure aqueous vapor.	Temperatures.
	mm.	*mm.*	°C.
Sept. 9 to Sept. 22	10. 5	5. 52	23. 0
Sept. 24 to Oct. 7	5. 2	3. 52	13. 6
Oct. 8 to Oct. 21	5. 2	3. 22	15. 4
Oct. 21 to Nov. 9	5. 0	4. 30	17. 1

It is to be regretted that at this very time, when all these changes were occurring, we made a radical change in the observing apparatus, for on September 23 we substituted for the bolometer which had been in use on Mount Wilson since 1905 the bolometer which was employed in the Mount Whitney and Algerian expeditions. We made this change because the Algerian bolometer was less subject to prejudical influence from wind. But had we known how many other changes were occurring at the same time, it is certain that we would not have made a change of apparatus too. We have thought it necessary, on account of this, to investigate very thoroughly the merit of the solar-constant determinations succeeding September 23, and we find the following facts to verify their accuracy.

First, empirical determinations of the solar constant from pyrheliometry and psychrometry at Arequipa in Peru[8] indicate that the values subsequent to September 23 were lower than those prior to that date, and by about the same amount as do the Mount Wilson observations. Second, we have determined an empirical formula for the solar constant from Mount Wilson pyrheliometry and psychrometry. This formula has been worked out solely by the use of observations of 1910, 1911, and 1912, and does not depend in any way on bolometric observations of 1913, except that we chose days of the earlier years for which the precipitable water had values comparable with those of 1913. This formula gives the same change in solar-constant values at about September 23 that is indicated by the bolometric work itself. Third, we felt a suspicion that the determinations of the water-vapor absorption in the bolographic work might be interfered with by some change in the excellence of the definition of the spectroscope. Instead of employing with the usual constants Mr. Fowle's method of determining these absorption effects in the bolographs, from measurements on the band $\rho\sigma\tau$, the areas of the absorption bands were actually measured on many plates, just as we did formerly in all our bolographic reductions, and we thus determined new constants applicable to the last part of 1913. But no substantial change occurred in our conclusion regarding the fall of the solar-constant values on and after September 24.

We therefore see no reason to doubt that the days from September 9 to the end of 1913 are as homogeneous as any other series of our measurements, and we believe that the great drop of the solar constant which is indicated to have occurred just after September 23 is a real one.

Figures 28, 29, 30, and 31 show the solar-constant values and the solar-contrast values of 1913 and 1914 plotted as functions of the time and also as functions of each other. From figures 28 and 29 the increase of the solar-constant values by 1 per cent corresponds to an increase of solar-contrast values of 1913 and 1914 as follows:

Year.	Change of solar constant.	Change of solar-contrast number.
1913	+1 per cent.	+17
1914	+1 per cent.	+29

[8] See "Arequipa Pyrheliometry," Smithsonian Miscellaneous Collections, vol. 65, no. 9.

The factors of correlation (omitting $\lambda = 0.3737$ and 1.008) are as follows:

$$1913:\ r = 0.601 \pm 0.067$$
$$1914:\ r = 0.213 \pm 0.080$$

The reader will recall that the method of deriving these contrast values is such that algebraically increased contrast numbers correspond really with decreased solar contrast.

Let us now restate these logarithmic results in ordinary terms. Imagine that the spectroscope was dispensed with, and that the contrast of brightness was determined for the solar

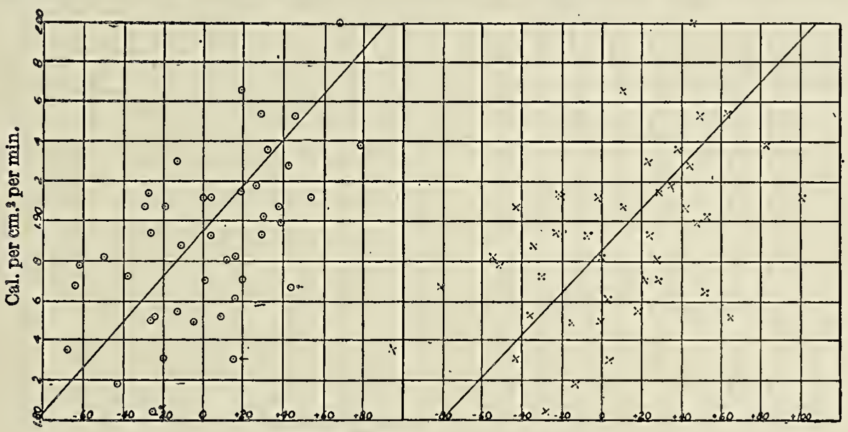


FIG. 28.—Variations of solar constant and solar contrast in 1913.[9]

radiation as a whole, and not for particular wave lengths. Let us further suppose that all the drift curves so obtained during 1913 and 1914 were reduced to unit intensity at the center of the solar disk. We should then find, still confining ourselves to a consideration of the short-period variations, that in 1913 an increase of 1 per cent in the solar constant of radiation corresponds with a decrease of the ordinate of the drift curve at 92 per cent out on the radius of 0.35 per cent.

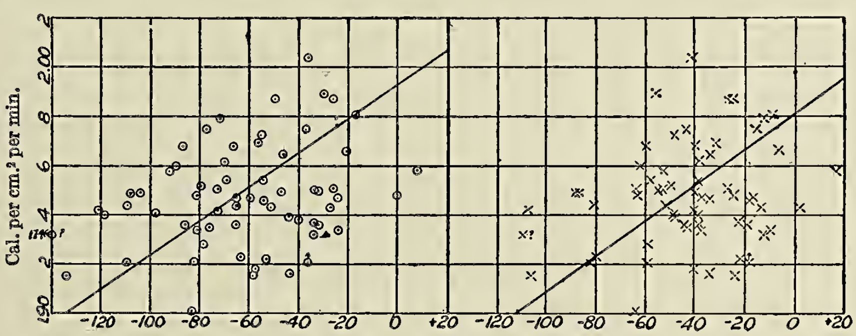


FIG. 29.—Variations of solar constant and solar contrast in 1914.[9]

The results of 1914 indicate a larger ratio of change of contrast compared to change of solar constant than those of 1913. This may be possibly a real difference caused in the sun, but it should be noted that the range of variation in 1914 was so small that the error of the determination of this ratio is much larger than it was in 1913. It is probable that the numerous values which will be found from observations of 1915 will enable us to give a more satisfactory conclusion on this point.

[9] Circles represent simple mean contrast numbers, omitting wave lengths 0.3737 and 1.008μ. Crosses represent weighted means of all wave lengths. Arrows indicate that a certain probability exists that the points marked should be moved in the direction shown.

We now come to the consideration of the question why the ratio of change of contrast from year to year with respect to change of solar constant differs in its sign from the ratio of change of contrast from day to day with reference to the corresponding change in the solar constant. As stated above, in years when the solar constant was high the solar contrast was greater than usual, while, as just stated, during 1913 and 1914 short-period temporary increases of the solar constant of radiation were attended by decrease in the solar contrast. This indicates two causes at work in the sun. We are inclined to suggest the following hypothesis:

Attending the long-period changes of solar activity indicated by prevalence of sun spots, faculæ, prominences, etc., there is, it may be assumed, a change of the effective solar radiating temperature. Higher effective radiating temperatures should prevail at times when increased solar activity brings faster the hot material to the surface to radiate. It is clear that if the solar temperature was zero, the contrast of brightness would be zero, and the higher the temperature, the higher the contrast and the higher the solar constant of radiation.

Turning now to a consideration of the short-period changes, it was the older view that the difference of brightness between the center and the edge of the solar disk was produced by an absorbing atmosphere or envelope. We prefer, however, to regard the decrease of brightness toward the edge of the sun as mainly a consequence of decreased effective temperature of the radiating surface. We suppose that the depth to which one looks at the center of the solar disk is very considerable, and that the limit of it is reached when the molecular scattering cuts off the ray. The same quantity of molecular scattering will be found in a very much less radial depth near the edge of the sun, because the line of sight there is oblique, so that a comparatively thin layer viewed obliquely will furnish the necessary number of molecules to cut off the radiation.

But while holding these views, we admit that the escape of radiation depends also on the transparency of the outer solar envelope. If now the transparency of this envelope increases, the solar constant of radiation must increase also; but the percentage increase of the intensity of solar rays will be greatest near the edge of the sun, where the path in these imperfectly transparent layers is longest. Thus it would happen that increased transparency of the outer solar layers would produce at the same time increased values of the solar constant of radiation and decreased contrast of brightness between the center and edge of the sun.

The two contrary effects we have been discussing may sometimes neutralize each other, but it is not to be expected that they will exactly neutralize each other for all wave lengths. Hence, we may find, with very high values of the solar constant of radiation, a contrast almost exactly, on the whole, equal to that which prevailed in the mean in the year 1913, but the different wave lengths may differ slightly in their behavior, some indicating a greater contrast than the mean of 1913, others less.

In our former publications on this subject (see vols. II and III of the Annals) we have already considered the possibility of short-period irregular fluctuations of contrast and arrived at opposite conclusions from the two sets of data then published. Both sets of data, however, are so far inferior in accuracy to those we are now publishing that we withdraw altogether those former conclusions in favor of the ones which we now advance.

DISTRIBUTION EXPERIMENTS, 1915 TO 1920.

The investigations just described have been continued in all the subsequent years at Mount Wilson. With the introduction of the vacuum bolometer, differences occurred in the scale of ordinates of the solar distribution curves observed, and in the later years it became possible to produce the U curves at all wave lengths with central heights exceeding 10 centimeters. Thus in the later work errors were minimized. In 1920 the final change was made of omitting the two extreme wave lengths, the ultra-violet and the extreme infra-red one, respectively, of the seven which had hitherto been observed. Each of the remaining five places was observed three times independently on each day instead of twice, as before. In general the observations of the drift curves were woven into the unoccupied intervals of the observing schemes every day in which solar constant observations were made, so that the results of the two long series of independent solar observations were simultaneously obtained and entirely suitable for direct comparison together.

We give first of all in Tables 73 and 74 the ratios of the mean results for the several years to the mean results of 1913 for various places along the solar radius and for various wave lengths. These tables are comparable to Table 68, page 222 Instead, however, of using all of the data for every year, we have selected groups of 5 days representing the highest, the mean, and the lowest contrast conditions, respectively, which prevailed in the different years. The general mean of these representative data is also given for each year.

TABLE 73.—*Mean distribution of radiation along the solar diameter for groups of high, medium, and low contrast, compared to 1913 values.*

Wave length.	High dates: Aug. 25, Sept. 27, 28, Oct. 8, 16, 1915.						Medium dates: July 3, 4, Aug. 17, 24, Oct. 11, 1915.						Low dates: June 10, 27, July 12, Aug. 11, 20, 1915.					
	Place on solar radius.						Place on solar radius.						Place on solar radius.					
	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035
μ																		
0.3737	0.9972	1.0009	0.9945	0.9908	1.0032	1.0035	0.9984	1.0009	0.9993	1.0009	1.0088	1.0134	1.0025	0.9963	0.9952	0.9915	0.9952	0.9961
.4265	0.9986	1.0007	1.0062	1.0102	1.0172	1.0205	0.9991	1.0019	0.9968	1.0000	0.9988	1.0042	1.0005	1.0002	0.9986	0.9986	0.9975	0.9966
.5062	0.9984	1.0014	1.0028	1.0042	1.0104	1.0111	1.0005	1.0000	1.0002	1.0025	1.0074	1.0053	0.9993	1.0005	0.9984	0.9977	0.9998	1.0007
.5955	1.0002	0.9998	1.0037	1.0055	1.0090	1.0100	0.9995	1.0009	1.0016	1.0030	1.0072	1.0065	1.0005	0.9979	1.0014	1.0005	1.0030	1.0035
.6702	0.9982	1.0000	1.0037	1.0005	1.0044	1.0065	0.9988	1.0005	1.0016	1.0028	1.0046	1.0051	1.0035	0.9936	0.9938	0.9915	0.9940	0.9943
.8580	1.0009	0.9998	1.0005	0.9988	1.0019	1.0046	1.0019	0.9995	0.9984	0.9986	0.9991	0.9988	1.0025	0.9982	0.9963	0.9970	0.9961	0.9982
1.0080	1.0007	1.0002	1.0009	1.0007	1.0028	1.0037	0.9998	0.9993	1.0007	1.0032	1.0044	1.0058	0.9991	1.0005	1.0009	0.9995	1.0009	1.0012

Wave length.	High dates: Sept. 8, 9, 10, 11, 12, 1916.						Medium dates: Aug. 29, 30, Sept. 1, 3, 4, 1916.						Low dates: Aug. 19, 20, 21, 22, 27, 1916.					
	Place on solar radius.						Place on solar radius.						Place on solar radius.					
	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035
μ																		
0.3737	0.9968	1.0021	1.0069	1.0109	1.0205	1.0259	0.9988	1.0046	1.0037	1.0030	1.0097	1.0062	0.9954	1.0018	0.9974	0.9879	0.9924	0.9710
.4265	1.0002	0.9986	1.0005	1.0007	0.9979	0.9972	1.0005	0.9991	0.9956	0.9954	0.9945	0.9863	1.0037	0.9972	0.9895	0.9824	0.9788	0.9647
.5062	0.9986	1.0007	1.0014	1.0014	1.0012	0.9970	1.0016	0.9995	0.9966	0.9968	0.9968	0.9883	1.0018	0.9986	0.9920	0.9897	0.9829	0.9716
.5955	0.9991	0.9998	1.0028	1.0012	1.0025	1.0018	1.0014	0.9982	0.9975	0.9968	0.9979	0.9963	1.0012	0.9991	0.9945	0.9915	0.9874	0.9795
.6702	1.0007	0.9993	1.0009	1.0005	1.0007	0.9982	1.0014	0.9982	0.9975	0.9954	0.9954	0.9892	1.0023	0.9961	0.9949	0.9890	0.9858	0.9719
.8580	0.9991	1.0009	1.0005	1.0048	1.0018	1.0019	1.0005	0.9986	0.9988	1.0007	1.0007	0.9979	1.0018	0.9991	0.9986	0.9975	0.9968	0.9906
1.0080	0.9982	1.0009	1.0055	1.0067	1.0079	1.0058	0.9984	1.0014	0.9795	1.0053	1.0058	1.0053	1.0009	1.0000	0.9988	0.9984	0.9897	0.9795

76960°—22——16

TABLE 73.—*Mean distribution of radiation along the solar diameter for groups of high, medium, and low contrast, compared to 1913 values*—Continued.

Wave length.	High dates: July 18, Aug. 19, 28, 29, Sept. 3, 1917.						Medium dates: Aug. 2, 11, Sept. 20, 22, 24, 1917.						Low dates: July 3, 4, 5, Aug. 9, Sept. 13, 1917.					
	Place on solar radius.						Place on solar radius.						Place on solar radius.					
	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035
μ																		
0.3737	0.9917	1.0018	1.0137	1.0123	1.0273	1.0320	0.9982	0.9970	0.9988	1.0028	1.0039	1.0002	1.0002	1.0005	0.9986	0.9993	1.0005	1.0037
0.4265	1.0007	0.9993	0.9986	1.0044	1.0005	0.9986	1.0014	0.9963	0.9908	0.9904	0.9904	0.9876	1.0046	0.9968	0.9897	0.9908	0.9858	0.9770
0.5062	1.0023	1.0000	0.9979	1.0016	1.0016	1.0046	0.9991	0.9984	0.9975	1.0009	1.0025	1.0032	1.0012	0.9995	0.9938	0.9936	0.9913	0.9854
0.5955	0.9984	1.0009	1.0046	1.0074	1.0078	1.0109	1.0014	0.9984	0.9984	0.9982	0.9972	0.9982	1.0005	0.9984	0.9952	0.9970	0.9945	0.9899
0.6702	1.0012	0.9988	1.0007	0.9991	1.0018	1.0002	1.0025	0.9970	0.9984	0.9972	0.9963	0.9943	1.0014	0.9979	0.9949	0.9940	0.9897	0.9854
0.8580	0.9995	1.0002	1.0028	1.0038	1.0049	1.0002	1.0009	0.9986	0.9979	1.0009	0.9975	0.9945	1.0018	0.9991	0.9966	0.9963	0.9938	0.9917
1.0080	0.9986	1.0009	1.0032	1.0055	1.0078	1.0066	0.9991	1.0002	1.0035	1.0053	1.0069	1.0139	1.0007	0.9968	1.0014	1.0048	1.0039	1.0028

Wave length.	High dates: June 29, July 25, 27, Aug. 21, 22, 1918.						Medium dates: July 5, 14, Aug. 9, 10, 13, 1918.						Low dates: July 4, 21, 20, Aug. 18, 28, 1918.					
	Place on solar radius.						Place on solar radius.						Place on solar radius.					
	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035
μ																		
0.3737	0.9995	1.0023	0.9979	1.0051	1.0155	1.0144	0.9993	1.0018	1.0023	1.0023	1.0148	1.0216	1.0018	1.0009	0.9949	0.9995	1.0076	1.0156
0.4265	0.9995	0.9998	1.0046	1.0069	1.0104	1.0079	1.0023	0.9986	0.9966	0.9936	0.9883	0.9881	1.0018	0.9991	0.9897	0.9895	0.9881	0.9793
0.5062	1.0009	0.9995	0.9963	1.0007	0.9998	1.0002	1.0018	0.9988	0.9952	0.9956	0.9949	0.9970	1.0035	0.9986	0.9931	0.9952	0.9998	0.9940
0.5955	0.9988	1.0016	1.0025	1.0018	1.0030	1.0028	1.0007	0.9991	0.9972	0.9945	0.9931	0.9940	1.0019	0.9984	0.9977	0.9952	0.9956	0.9888
0.6702	1.0030	0.9979	0.9991	1.0000	1.0016	1.0005	1.0032	0.9972	0.9968	0.9945	0.9945	0.9949	1.0025	0.9970	0.9940	0.9938	0.9952	0.9913
0.8580	0.9991	1.0002	1.0028	1.0037	1.0065	1.0042	1.0009	0.9991	0.9993	0.9984	0.9984	1.0025	1.0023	0.9979	0.9959	0.9968	0.9956	0.9892
1.0080	0.9991	1.0005	1.0019	1.0035	1.0028	1.0060	0.9988	1.0007	1.0014	1.0025	1.0039	1.0060	0.9998	1.0005	1.0023	1.0046	1.0055	1.0067

Wave length.	High dates: June 21, Aug. 27, Sept. 11, 16, 19, 1919.						Medium dates: June 18, 28, July 14, 24, Aug. 3, 1919.						Low dates: June 26, July 1, 3, 6, Aug. 19, 1919.					
	Place on solar radius.						Place on solar radius.						Place on solar radius.					
	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035
μ																		
0.3737	0.9933	1.0007	1.0294	1.0428	1.0563	1.0990	0.9938	1.0009	1.0219	1.0366	1.0632	1.0752	0.9940	1.0055	1.0188	1.0216	1.0335	1.0469
0.4265	0.9984	1.0009	1.0035	1.0116	1.0109	1.0179	0.9993	0.9995	0.9986	0.9940	0.9922	0.9883	1.0037	0.9968	0.9895	0.9874	0.9865	0.9795
0.5062	1.0007	0.9986	0.9982	0.9995	1.0007	1.0032	1.0019	0.9982	0.9938	0.9936	0.9943	0.9982	1.0032	0.9977	0.9870	0.9824	0.9795	0.9732
0.5955	1.0007	1.0005	0.9995	1.0002	1.0007	1.0019	1.0002	1.0019	0.9988	0.9968	1.0014	1.0019	1.0014	0.9977	0.9931	0.9870	0.9858	0.9831
0.6702	1.0014	0.9988	0.9968	0.9966	0.9956	0.9940	1.0032	0.9975	0.9954	0.9922	0.9961	0.9904	1.0035	0.9975	0.9906	0.9858	0.9872	0.9858
0.8580	0.9986	1.0016	1.0009	1.0014	0.9988	0.9986	1.0019	0.9977	0.9984	0.9982	0.9966	0.9956	1.0025	0.9993	0.9931	0.9901	0.9883	0.9822
1.0080	0.9977	1.0002	0.9991	1.0009	0.9982	0.9977	1.0016	0.9991	0.9993	0.9975	0.9984	0.9986	1.0019	0.9979	0.9943	0.9913	0.9947	0.9915

Wave length.	High dates: July 17, Aug. 3, 4, 5, 7, 1920.						Medium dates: July 19, 21, Aug. 13, 20, 21, 1920.						Low dates: Aug. 15, 19, Sept. 2, 3, 4, 1920.					
	Place on solar radius.						Place on solar radius.						Place on solar radius.					
	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035
μ																		
0.4265	0.9972	1.0012	1.0025	1.0039	1.0134	1.0156	1.0009	0.9988	0.9984	0.9952	0.9956	0.9947	1.0030	0.9988	0.9922	0.9908	0.9943	0.9929
0.5062	0.9986	1.0002	1.0035	1.0025	1.0062	0.9986	0.9998	0.9993	0.9961	0.9936	0.9945	0.9940	1.0028	0.9956	0.9920	0.9911	0.9943	0.9924
0.5955	0.9986	0.9991	1.0018	1.0030	1.0046	1.0086	1.0005	0.9988	1.0005	0.9977	1.0000	1.0014	1.0009	0.9991	0.9975	0.9947	0.9968	0.9947
0.6702	1.0000	0.9988	1.0012	0.9998	1.0030	1.0009	1.0014	0.9977	0.9961	0.9927	0.9956	0.9952	1.0019	0.9982	0.9947	0.9904	0.9922	0.9899
0.8580	1.0002	0.9995	1.0039	1.0030	1.0047	1.0060	0.9993	0.9995	1.0005	0.9993	0.9991	0.9986	1.0030	0.9984	0.9975	0.9966	0.9977	0.9949

The following additional medium-to-high group early in the season of 1916 was selected to see if the break in scale, so apparent in the plot for this year, was attended by any notable change in distribution not recognized from the slant values given below. Apparently there was none such.

Wave length.	Medium dates: July 5, 6, 7, 8, 9, 1916.					
	Place on solar radius.					
	0.2	0.55	0.75	0.825	0.875	1.0035
μ						
0. 3737	0. 9938	1. 0025	1. 0032	1. 0023	0. 9970	0. 9795
0.4265	0.9998	0.9995	0.9988	0.9984	1.0021	1.0007
0. 5062	1. 0005	0. 9986	0. 9984	0. 9977	1. 0035	1. 0028
0. 5955	0. 9991	1. 0000	1. 0007	0. 9995	1. 0025	0. 9991
0. 6702	1. 0007	0. 9988	1. 0005	0. 9963	1. 0012	0. 9986
0. 8580	0. 9988	1. 0007	1. 0016	1. 0009	1. 0023	1. 0014
1. 0080	0. 9995	1. 0009	1. 0009	1. 0028	1. 0060	1. 0062

TABLE 74.—*Mean distribution from all data of Table 73.*

Wave length.	1915						1916						1917					
	Place on solar radius.						Place on solar radius.						Place on solar radius.					
	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035
μ																		
0.3737......	0. 9994	0. 9994	0. 9963	0. 9944	1. 0024	1. 0043	0. 9962	1. 0027	1. 0028	1. 0010	1. 0074	0. 9956	0. 9967	0. 9998	1. 0037	1. 0048	1. 0106	1. 0120
0.4265......	0. 9994	1. 0009	1. 0005	1. 0029	1. 0045	1. 0071	1. 0010	0. 9986	0. 9961	0. 9942	0. 9933	0. 9872	1. 0022	0. 9975	0. 9930	0. 9952	0. 9922	0. 9877
0.5062......	0. 9994	1. 0006	1. 0005	1. 0015	1. 0059	1. 0057	1. 0006	0. 9994	0. 9971	0. 9964	0. 9961	0. 9899	1. 0009	0. 9993	0. 9964	0. 9987	0. 9985	0. 9977
0.5955......	1. 0001	0. 9995	1. 0022	1. 0030	1. 0064	1. 0067	1. 0002	0. 9993	0. 9989	0. 9977	0. 9976	0. 9942	1. 0001	0. 9992	0. 9994	1. 0009	0. 9998	0. 9997
0.6702......	1. 0002	0. 9980	0. 9997	0. 9983	1. 0010	1. 0020	1. 0013	0. 9981	0. 9984	0. 9953	0. 9958	0. 9895	1. 0017	0. 9979	0. 9980	0. 9968	0. 9959	0. 9933
0.8580......	1. 0018	0. 9992	0. 9984	0. 9981	0. 9990	1. 0005	1. 0000	0. 9998	0. 9999	1. 0010	1. 0004	0. 9979	1. 0007	0. 9993	0. 9991	1. 0003	0. 9987	0. 9955
1.0080......	0. 9999	1. 0000	1. 0008	1. 0011	1. 0027	1. 0036	0. 9992	1. 0008	0. 9962	1. 0033	1. 0023	0. 9992	0. 9995	0. 9993	1. 0027	1. 0052	1. 0062	1. 0078

Wave length.	1918						1919						1920					
	Place on solar radius.						Place on solar radius.						Place on solar radius.					
	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035	0.2	0.55	0.75	0.825	0.875	1.0035
μ																		
0.3737......	1. 0002	1. 0017	0. 9984	1. 0023	1. 0126	1. 0172	0. 9937	1. 0024	1. 0234	1. 0337	1. 0510	1. 0737	....	....	....	....	....	....
0.4265......	1. 0012	0. 9992	0. 9970	0. 9967	0. 9956	0. 9918	1. 0005	0. 9991	0. 9972	0. 9977	0. 9965	0. 9952	1. 0004	0. 9996	0.9977	0. 9966	1. 0011	1. 0011
0.5062......	1. 0021	0. 9990	0. 9949	0. 9972	0. 9982	0.9971	1.0019	0.9982	0. 9930	0. 9918	0. 9915	0. 9915	1. 0004	0. 9984	0. 9972	0. 9957	0. 9983	0. 9950
0.5955......	1. 0005	0. 9997	0. 9991	0. 9972	0. 9972	0. 9952	1. 0008	1. 0000	0. 9971	0. 9947	0. 9960	0. 9956	1. 0000	0. 9990	0. 9999	0. 9985	1. 0005	1. 0016
0.6702......	1. 0029	0. 9974	0. 9966	0. 9961	0. 9971	0. 9956	1. 0027	0. 9979	0. 9943	0. 9915	0. 9930	0. 9901	1. 0011	0. 9982	0. 9973	0. 9943	0. 9969	0. 9953
0.8580......	1. 0008	0. 9991	0. 9993	0. 9996	1. 0002	0. 9986	1. 0010	0. 9995	0. 9975	0. 9966	0. 9946	0. 9921	1. 0008	0. 9991	1. 0006	0. 9996	1. 0005	0. 9998
1.0080......	0. 9992	1. 0006	1. 0019	1. 0035	1. 0041	1. 0062	1. 0004	0. 9991	0. 9976	0. 9966	0. 9971	0. 9959	....	....	....	....	....	....

We now give in Tables 75 to 82, for all years, 1913 to 1920, inclusive, the mean tangents or slant numbers at the separate wave lengths for individual days, as described under the caption "Changes of Distribution from Day to Day," and illustrated in figure 27. These values are determined as already described on the basis of the departures from the mean distribution determined in 1913. The values given are numbers, not the logarithms which are read off the plots directly. If pointed off two places they give the percentage departures at the sun's edge from the standard forms of 1913. See, for example, Table 83, where this is done. The tables include also a mean tangent or slant number for each day representative of the combined data for the five middle wave lengths. These results were combined for the years 1913 and 1914 with weights as stated above, but for the succeeding years 1915 to 1920 with the following weights:

Wave length, μ..........	0. 4265	0. 5062	0. 5955	0. 6702	0. 8580
Weights................	0. 7	1. 0	1. 0	1. 0	1. 0

In addition, we give the value of the solar constant for the day. When both Mount Wilson and Calama values were available, as for many days of 1918, 1919, and 1920, we first reduced the Calama values for the difference of time between the observations. For example, the Calama observations were usually taken one-eighth day prior to those at Mount Wilson, and hence one-eighth part of the change of the solar constant toward the next succeeding day was in such cases applied. The mean was then taken, allowing corrected Calama values double the weight of the Mount Wilson E_0' values.

In figures 30 to 34 solar-constant and solar-contrast results are plotted with respect to the time scale, and with them the Wolf-Wolfer sun-spot numbers. In plotting the solar-constant values of 1912 to 1917, inclusive, the grade of the solar-constant values is indicated by the following conventions:

Grade.	e.+	e.	e−.	v. g.+	v. g.	Other grades.
Symbol.	8 armed dotted circle.	8 armed circle.	4 armed circle.	2 armed circle.	Circle.	Dot.

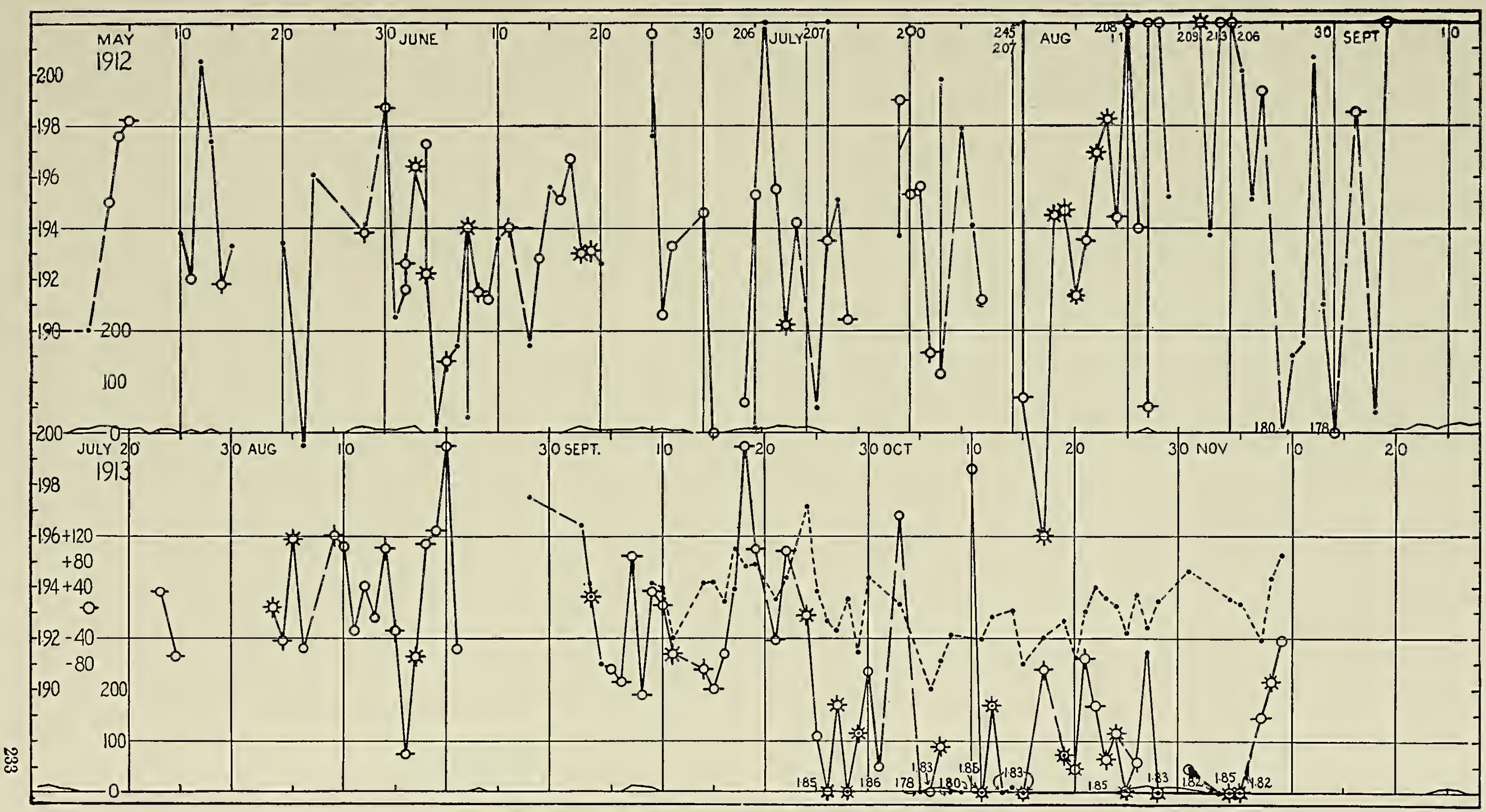


FIG. 30.—Solar-constant, solar-contrast, and sun-spot numbers, 1912–1913.

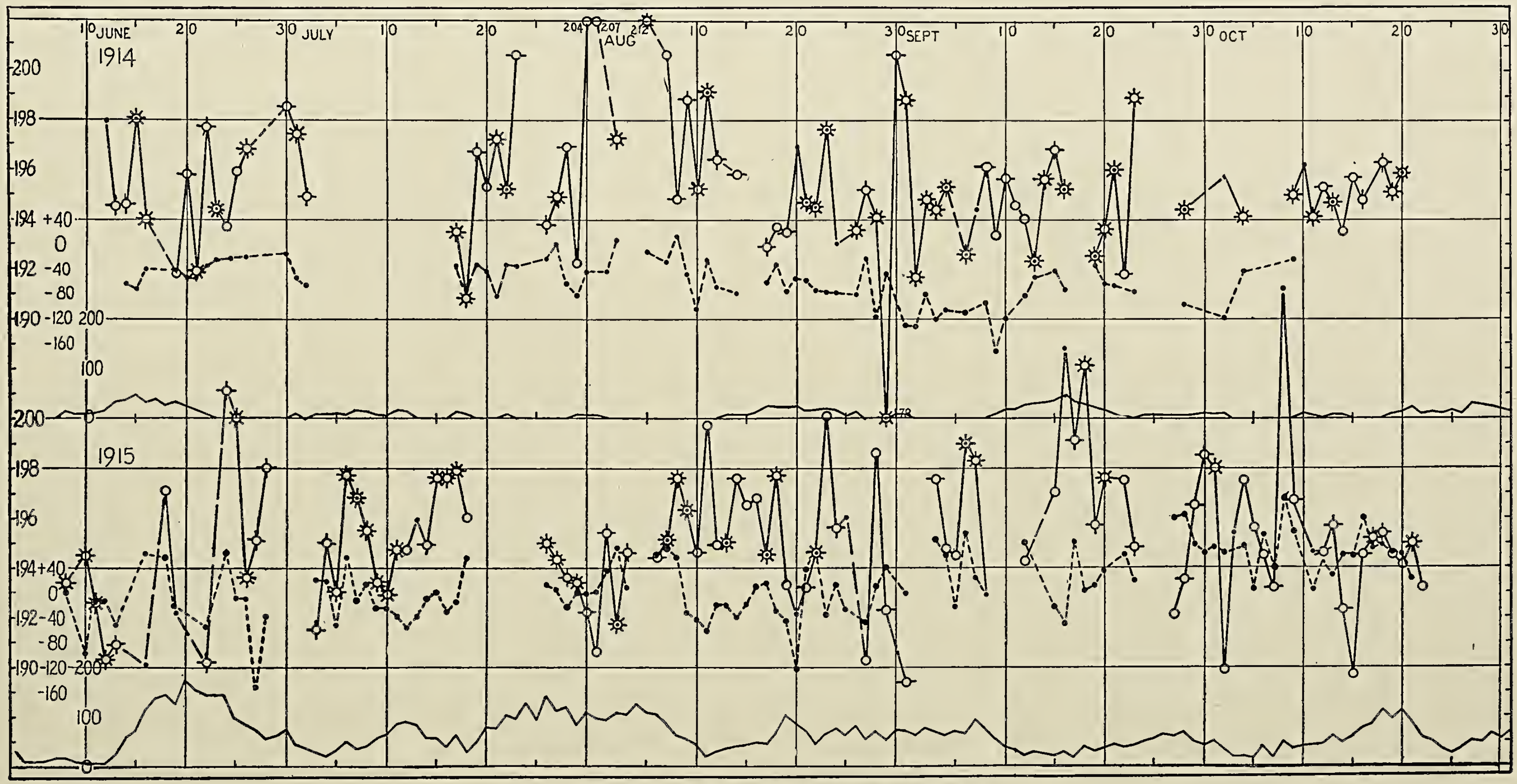


FIG. 31.—Solar-constant, solar-contrast, and sun-spot numbers, 1914–1915.

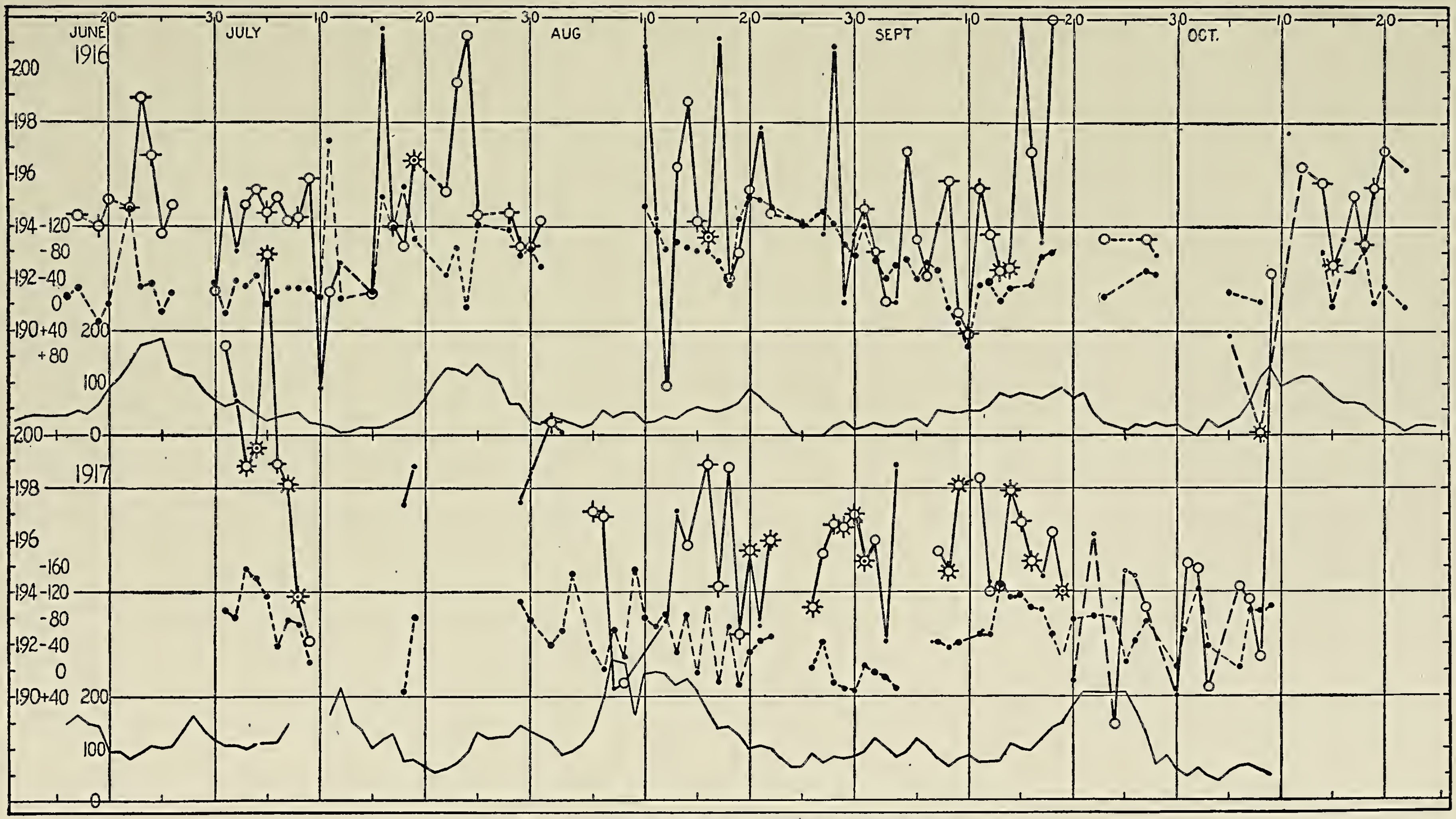


FIG. 32.—Solar-constant, solar-contrast, and sun-spot numbers, 1916-1917.

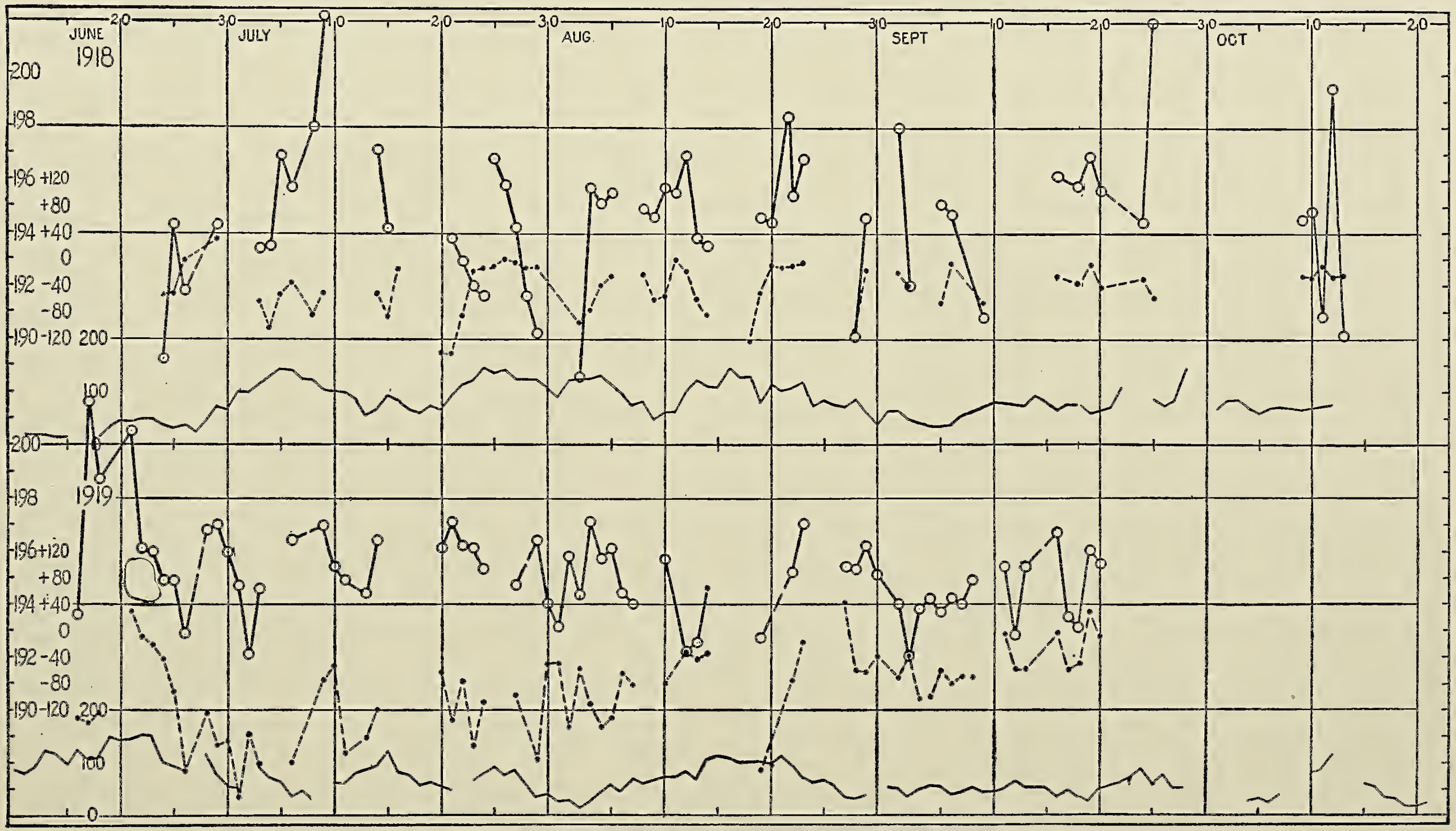


FIG. 33.—Solar-constant, solar-contrast, and sun-spot numbers, 1918–1919.

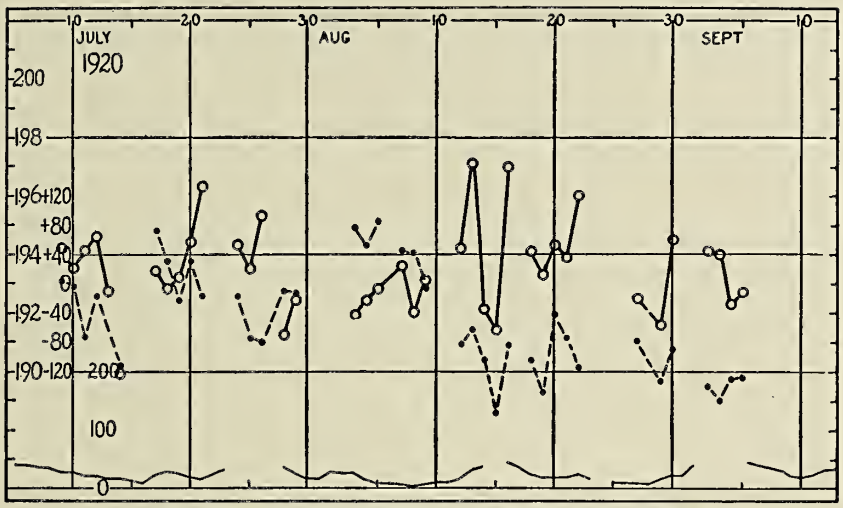


FIG. 34.—Solar-constant, solar-contrast, and sun-spot numbers, 1920.

TABLE 75.—*The daily solar-contrast values, 1913.*

Date.	Wave lengths in μ. 0.374	0.426	0.506	0.595	0.607	0.858	1.008	Weighted mean of departures.[1]	Solar constant (calories).
	Departures.								
Sept. 9	127	....	− 44	....	100	....	....	42	1.936
10	− 81	− 53	30	− 46	....	− 51	100	36	1.933
11	−219	130	−109	58	− 53	− 28	14	− 41	1.914
14	55	53	21	67	137	− 90	42	46	1.908
15	165	12	60	79	− 25	69	18	46	1.900
16	411	95	100	− 30	46	58	109	16	1.914
17	392	304	95	134	− 12	−127	67	100	1.939
18	46	172	−160	32	153	139	− 16	71	1.995
19	160	86	− 5	60	− 25	7	130	74	1.995
21	309	79	− 14	37	− 58	53	9	13	1.919
22	392	48	58	62	− 14	76	− 28	49	1.954
24	97	125	328	60	− 18	5	155	167	1.929
25	14	− 18	90	− 7	− 14	5	44	32	1.882
26	90	− 7	− 53	− 83	97	23	− 62	− 15	1.849
27	− 21	− 23	− 32	− 23	....	....	....	− 28	1.894
28	− 53	− 81	− 5	− 5	− 5	42	76	22	1.855
29	− 7	− 55	− 76	− 74	0	− 32	− 48	− 62	1.883
30	−125	261	28	− 97	67	−118	25	54	1.907
Oct. 3	28	83	21	46	18	− 74	7	12	1.968
6	− 86	− 81	− 67	−104	−158	− 79	− 62	−120	1.835
7	14	−181	− 42	− 97	− 32	− 30	12	− 77	1.878
8	− 14	− 23	− 21	− 51	− 7	− 25	− 23	− 33	1.805
11	− 14	67	−111	− 37	16	− 53	− 23	− 41	1.853
12	−100	0	113	− 39	− 79	23	− 30	− 8	1.894
14	− 2	81	0	− 18	25	25	− 42	3	1.860
15	7	16	0	16	− 55	− 79	− 65	− 60	1.832
17	− 95	5	− 67	0	− 60	− 23	− 32	− 39	1.908

[1] These values differ from those published in Smithsonian Miscellaneous Collections, Vol. 66. The present values are formed from departures of all wave lengths but excluding poor and very poor observations.

TABLE 75.—*The daily solar-contrast values, 1913*—Continued.

Date.	Wave lengths in μ							Weighted mean of departures.	Solar constant (calories).
	0.374	0.426	0.506	0.595	0.607	0.858	1.008		
	Departures.								
Oct. 19	18	−137	− 16	− 23	− 5	− 9	2	− 12	1. 875
20	−181	−184	− 81	−100	− 76	0	− 21	− 72	1. 869
21	− 42	25	− 18	5	− 5	14	− 5	2	1. 912
22	32	69	− 30	86	− 32	58	7	40	1. 894
23	209	− 53	− 12	30	58	− 18	28	25	1. 873
24	35	− 37	− 42	55	51	− 5	− 18	9	1. 883
25	−144	− 69	− 14	30	− 95	144	0	− 32	1. 850
26	− 18	48	− 12	− 46	53	55	39	29	1. 872
27	− 65	− 42	− 67	− 2	− 51	28	9	− 22	1. 915
28	−160	− 12	74	88	− 21	− 53	2	18	1. 831
31	18	100	35	95	25	....	....	64	1. 869
Nov. 4	349	48	148	25	30	53	21	19	1. 853
5	18	−165	− 53	− 72	55	21	35	12	1. 818
7	−191	46	− 74	− 28	42	− 42	− 32	− 45	1. 889
8	116	− 7	− 7	69	144	86	− 16	53	1. 903
9	−118	18	− 28	18	28	97	51	91	1. 919

TABLE 76.—*The daily solar-contrast values, 1914.*

Date.	Wave lengths in μ.							Weighted mean of departures.	Solar constant (calories).
	0.374	0.426	0.506	0.595	0.607	0.858	1.008		
	Departures.								
June 14	0	− 12	− 28	− 85	− 25	−173	− 41	− 65	1. 946
15	103	− 46	− 57	....	−112	23	....	− 72	1. 980
16	− 30	− 44	− 78	−112	3	25	16	− 40	1. 940
19	− 12	− 89	− 71	....	− 7	− 7	212	− 43	1. 918
20	−101	− 71	71	− 96	− 69	−103	9	− 54	1. 958
21	....	− 57	−128	− 71	− 14	− 16	− 21	− 57	1. 919
22	....	− 21	−124	− 57	−108	126	− 7	− 37	1. 977
23	− 21	− 62	− 30	− 62	18	2	73	− 27	1. 944
26	− 9	− 5	− 9	135	− 9	− 60	− 64	− 21	1. 968
30	− 18	− 53	− 53	39	− 9	− 7	− 12	− 17	1. 985
July 1	−160	− 78	− 71	− 5	− 12	−110	− 37	− 55	1. 974
2	− 18	−130	−176	− 28	− 21	28	− 32	− 65	1. 949
17	− 41	5	−130..	....	− 28	18	7	− 34	1. 935
18	− 99	−126	− 2	−119	−153	− 14	− 62	− 83	1. 908
19	−234	−119	− 32	− 5	14	− 28	−139	− 34	1. 967
20	....	....	− 83	− 32	−103	28	− 46	− 47	1. 953
21	− 44	−167	− 67	− 83	−139	− 60	− 46	− 87	1. 972
22	− 7	− 64	− 21	− 28	− 41	− 9	−160	− 33	1. 952
23	−273	− 55	− 14	− 53	−101	44	− 41	− 36	2. 006
26	−160	− 16	− 18	− 5	−185	67	32	− 24	1. 938
27	− 64	− 30	250	41	−167	− 94	− 76	0	1. 949

TABLE 76.—*The daily solar-contrast values, 1914*—Continued.

Date.	Wave lengths in μ							Weighted mean of departures.	Solar constant (calories).
	0.374	0.426	0.506	0.595	0.607	0.858	1.008		
	Departures.								
July 28	....	− 32	− 57	−110	− 73	− 60	− 5	− 66	1.969
29	− 28	− 30	− 28	− 85	−194	− 71	− 55	− 82	1.922
30	−335	− 64	− 73	− 37	− 23	− 34	− 14	− 46	2.035
Aug. 1	−472	− 23	− 64	− 71	− 60	− 7	− 23	− 45	2.069
2	....	− 23	− 9	64	0	− 2	− 16	6	1.972
5	−183	....	0	− 39	− 9	0	− 2	− 12	2.117
7	−142	− 25	− 41	− 32	− 18	− 34	−130	− 30	2.006
8	− 92	− 2	41	− 2	− 48	76	5	13	1.948
9	−151	− 55	− 18	− 76	− 96	7	32	− 49	1.988
10	−308	−192	− 60	− 64	− 96	−108	− 67	−104	1.952
11	− 5	69	−114	− 41	− 5	− 39	− 44	− 26	1.991
12	− 14	− 64	−146	− 14	− 83	− 44	− 16	− 70	1.964
14	− 57	−214	− 30	− 60	− 14	....	− 34	− 79	1.958
17	−362	− 44	−164	− 18	− 23	− 67	−114	− 63	1.929
18	− 28	− 14	− 37	− 7	− 12	− 99	− 5	− 34	1.937
19	− 18	−146	− 89	9	− 7	−149	− 7	− 76	1.935
20	− 5	− 41	− 7	− 44	−183	− 5	....	− 56	1.969
21	− 55	− 7	− 71	− 62	− 85	− 71	9	− 59	1.947
22	− 23	−155	− 92	− 67	16	− 67	2	− 73	1.945
23	− 25	− 30	− 51	− 21	−101	−183	14	− 77	1.976
24	−167	− 18	−137	− 39	−112	− 83	− 37	− 78	1.930
26	110	− 28	−219	− 99	− 34	− 25	− 5	− 81	1.936
27	−153	− 39	− 34	− 32	− 2	− 23	− 26	− 26	1.952
28	178	−114	−117	44	−243	−160	39	−118	1.941
29	....	−103	....	− 25	− 46	− 18	0	− 48	1.780
31	....	−137	−155	−133	−105	−135	−160	−133	1.988
Sept. 1	−201	− 92	−234	−185	−105	− 53	− 99	−134	1.917
2	−198	− 51	−162	− 57	....	− 53	− 37	− 81	1.948
3	−260	−126	−212	−117	−103	−137	− 69	−121	1.944
4	−368	−103	−144	−117	− 57	−119	− 23	−108	1.953
6	−273	−144	− 64	−126	....	−103	− 18	−109	1.924
8	−160	−266	0	− 14	....	....	− 16	− 93	1.961
9	−295	−176	−185	−146	−266	− 69	− 30	−174	1.934
10	....	....	−137	− 80	−139	....	− 60	−119	1.957
12	− 34	−228	− 76	− 23	− 21	− 83	5	− 86	1.940
13	−248	− 80	− 89	− 7	− 83	− 7	64	− 53	1.923
15	−171	−124	....	− 12	− 28	− 21	− 9	− 46	1.968
16	−173	− 16	− 62	−128	− 83	− 76	0	− 73	1.952
19	....	− 48	− 14	− 48	....	− 34	18	− 36	1.925
20	− 34	− 41	− 83	−101	−135	37	60	− 65	1.936
21	−228	− 60	− 71	− 99	−112	− 96	0	− 90	1.960
23	....	− 87	....	− 30	−237	....	−103	− 79	1.989
28	....	−293	133	−126	−180	−23	37	− 98	1.944
Oct. 2	....	−160	....	− 76	....	....	....	−118	1.957
4	....	16	....	−105	....	....	−228	− 48	1.941
9	....	30	− 51	55	− 48	−108	− 5	− 24	1.950

TABLE 77.—*The daily solar-contrast values, 1915.*

Date.	Wave lengths in μ — Departures. 0.374	0.426	0.506	0.595	0.607	0.858	1.008	Weighted mean of departures.	Solar constant (calories).
June 8	....	−193	67	35	35	....	....	0	1.934
10	42	−198	16	− 51	−191	−102	76	− 98	1.945
11	−174	− 30	95	144	−188	− 39	−28	− 4	1.926
12	− 21	− 17	7	0	0	− 75	−24	− 17	1.903
13	−116	−207	− 88	− 51	30	− 18	− 9	− 55	1.909
16	382	− 7	42	....	148	....	167	62	1.903
18	....	88	....	74	....	25	....	56	1.971
19	....	−146	....	− 58	55	14	....	− 22	1.922
22	− 62	−116	−111	67	− 58	− 76	49	− 56	1.902
24	233	144	81	55	−179	7	53	62	2.011
25	−100	− 76	−102	− 83	35	116	....	− 10	2.000
26	−123	− 16	− 14	....	....	....	−30	− 12	1.936
27	−340	− 7	−257	−111	−167	−179	7	−153	1.951
28	21	−130	123	5	− 25	−133	0	− 39	1.980
July 3	167	5	18	5	86	− 14	12	19	1.915
4	12	− 21	− 42	0	137	0	0	16	1.950
5	−109	− 65	− 53	2	104	− 95	9	− 54	1.930
6	−191	− 21	− 18	97	49	130	−14	55	1.977
7	−268	− 60	− 49	− 37	28	25	− 9	− 14	1.968
8	−228	− 14	− 16	− 42	76	44	23	13	1.955
9	− 58	− 25	− 81	− 93	− 62	90	49	− 29	1.934
10	151	− 70	− 18	0	− 28	− 28	−28	− 26	1.929
11	−123	− 86	− 42	12	−205	81	25	− 39	1.947
12	− 65	88	− 28	0	−209	− 93	7	− 58	1.947
13	....	−139	....	− 2	....	....	....	− 49	1.959
14	139	35	18	18	−146	25	−14	− 11	1.949
15	125	0	− 23	18	0	0	5	− 1	1.976
16	−297	− 65	− 42	− 35	− 9	− 25	−12	− 32	1.976
17	− 93	− 9	− 44	− 18	− 18	5	148	− 16	1.979
18	−120	127	5	35	58	70	35	55	1.960
26	79	134	− 30	39	23	− 44	2	14	1.950
27	− 9	− 35	79	23	− 25	− 25	−30	4	1.943
28	81	− 7	−155	− 18	76	− 28	−25	− 27	1.936
29	− 46	−127	25	− 9	− 23	44	−42	− 8	1.934
30	207	− 39	− 5	0	23	− 18	− 7	− 6	1.922
31	− 86	− 12	− 37	46	−111	86	49	− 1	1.906
Aug. 1	233	− 9	30	− 9	151	0	28	33	1.954
2	− 70	23	72	62	65	118	137	72	1.917
3	−146	81	0	− 25	− 16	16	139	7	1.946
6	− 58	141	14	125	− 53	97	28	61	1.944
7	− 35	240	53	116	− 51	51	81	70	1.951
8	−580	30	74	130	5	39	70	56	1.976
9	−280	−116	76	....	−141	0	0	− 36	1.963
10	65	−139	− 12	30	−139	− 12	25	− 47	1.946
11	−198	−153	− 23	111	−144	−120	12	− 63	1.997

TABLE 77.—*The daily solar-contrast values, 1915*—Continued.

Date.	Wave lengths in μ: 0.374	0.426	0.506	0.595	0.607	0.858	1.008	Weighted mean of departures.	Solar constant (calories).
	Departures.								
Aug. 12	− 28	− 9	− 9	....	− 55	− 5	0	− 19	1.949
13	−202	−162	− 30	132	30	−100	28	− 21	1.950
14	−106	− 70	−132	53	− 76	− 2	12	− 41	1.976
15	−139	−100	− 44	14	0	0	55	− 20	1.965
16	−233	− 58	93	74	− 58	− 18	0	9	1.968
17	12	109	−132	37	35	44	25	14	1.945
18	−375	− 62	− 16	18	−109	− 5	12	− 31	1.977
19	−189	12	−151	46	− 62	− 62	−18	− 47	1.933
20	35	− 55	−304	14	−116	−193	12	−125	1.921
21	−170	− 23	− 58	174	0	62	130	36	1.932
22	104	74	− 7	86	42	111	12	62	1.946
23	−273	− 81	−109	12	−120	70	102	− 37	2.001
24	0	0	9	39	9	0	30	11	1.956
25	−158	−120	81	62	− 62	−102	23	− 26	1.960
27	− 55	− 70	− 12	58	− 65	−137	12	− 48	1.903
28	−100	5	58	16	− 28	2	0	10	1.986
29	233	46	0	104	48	12	16	40	1.923
31	−351	− 14	− 14	58	0	− 44	35	− 4	1.894
Sept. 3	167	179	76	93	55	69	16	87	1.976
4	−104	257	30	93	− 28	18	−39	59	1.948
5	−328	− 12	− 60	− 60	− 42	35	−32	− 25	1.945
6	− 46	170	95	83	0	151	18	97	1.990
7	219	− 65	12	62	18	55	28	23	1.983
8	285	− 73	53	0	− 58	5	25	− 10	1.929
12	−495	− 51	− 48	195	167	97	72	80	1.942
15	−202	− 18	0	− 51	− 42	....	− 18	− 26	1.970
16	−280	−214	− 32	− 14	− 93	23	21	− 52	2.028
17	− 83	− 30	186	116	....	37	....	82	1.991
18	− 81	−111	0	86	0	5	28	3	2.021
19	−299	162	104	2	− 65	− 86	69	9	1.957
20	−174	− 16	39	− 28	69	76	− 5	33	1.976
22	−127	162	0	90	− 74	139	−12	61	1.975
23	101	127	104	35	−153	0	58	15	1.948
27	− 49	72	174	139	97	111	88	120	1.921
28	58	−228	186	65	120	76	81	125	1.935
29	116	90	139	67	113	0	90	76	1.965
30	174	69	116	93	46	0	−28	61	1.985
Oct. 1	69	37	104	100	0	88	74	68	1.980
2	162	67	109	44	0	90	74	62	1.899
3	− 42	0	160	12	0	139	12	69	1.954
4	0	− 14	74	81	139	65	5	73	1.975
5	....	− 30	− 2	51	0	0	....	6	1.956
6	46	111	139	102	46	97	....	97	1.945
7	352	− 42	69	100	14	30	39	38	1.932
8	....	292	116	123	205	88	23	152	2.052

TABLE 77.—*The daily solar-contrast values, 1915*—Continued.

Date.	Wave lengths in μ. 0.374	0.426	0.506	0.595	0.607	0.858	1.008	Weighted mean of departures.	Solar constant (calories).
	Departures.								
Oct. 9	221	127	104	69	62	130	88	97	1.967
11	69	− 30	88	0	67	−104	0	1	1.946
12	....	0	67	55	46	67	23	50	1.946
13	....	0	97	46	0	− 12	− 12	26	1.957
14	151	375	132	67	−167	0	35	59	1.923
15	18	186	0	151	− 51	39	65	56	1.897
16	257	181	186	67	96	104	23	121	1.945
17	− 28	205	9	72	23	88	83	72	1.952
18	− 16	69	53	111	155	16	76	77	1.954
19	58	− 35	− 18	139	167	46	62	64	1.945
20	233	67	106	58	46	35	32	60	1.941
21	−352	162	− 30	− 25	97	− 35	35	22	1.950

TABLE 78.—*The daily solar-contrast values, 1916.*

Date.	Wave lengths in μ. 0.374	0.426	0.506	0.595	0.607	0.858	1.008	Weighted mean of departures.	Solar constant (calories).
	Departures.								
June 16	....	....	− 28	....	9	....	111	− 10	......
17	− 93	0	....	− 12	79	0	83	− 23	1.944
19	....	− 65	127	5	44	7	7	28	1.940
20	....	− 16	−132	55	....	69	....	0	1.950
22	....	−144	69	−186	−200	−254	−186	−147	1.947
23	....	− 88	....	23	− 65	0	18	− 26	1.989
24	....	−167	0	− 23	− 16	0	12	− 31	1.967
25	....	7	....	12	....	18	....	13	1.937
26	....	− 30	− 28	− 7	− 12	− 7	0	− 15	1.948
30	....	−174	− 12	− 32	− 12	16	28	− 32	1.915
July 1	....	− 58	− 39	0	70	70	46	16	1.954
2	....	− 23	− 74	− 12	− 86	7	− 12	− 36	1.930
3	....	−123	− 93	43	9	0	18	− 26	1.948
4	....	−151	− 65	0	− 23	− 16	7	− 43	1.954
5	....	0	18	− 30	− 30	23	23	− 2	1.945
6	....	12	− 79	− 23	0	7	30	− 17	1.951
7	....	− 32	− 42	− 23	− 93	55	18	− 22	1.942
8	−198	−104	− 39	0	− 12	9	14	− 23	1.943
9	....	− 23	....	− 58	....	0	....	− 25	1.958
10	....	−198	− 35	162	0	− 30	42	− 10	1.878
11	....	−328	−245	−221	−240	−257	0	−251	1.915
12	....	0	− 23	139	− 74	− 58	0	− 8	1.926
15	304	16	25	− 5	− 21	− 16	106	− 2	1.914
16	70	−292	−146	−162	− 44	−132	− 65	−164	2.016
17	− 23	−104	−172	− 51	−209	− 58	− 23	−116	1.940

TABLE 78.—*The daily solar-contrast values, 1916*—Continued.

Date.	Wave lengths in μ							Weighted mean of departures.	Solar constant (calories).
	0.374	0.426	0.506	0.595	0.607	0.858	1.008		
	Departures.								
July 18	− 9	−423	−123	−174	−155	−127	0	−181	1.932
19	14	−162	−116	−132	− 44	− 65	− 30	− 97	1.965
22	....	0	− 49	− 28	− 35	− 81	− 93	− 43	1.953
23	....	− 70	−162	− 93	− 88	− 42	70	− 89	1.995
24	70	116	−106	0	− 21	53	25	4	2.013
25	−139	−151	−162	− 16	−146	−144	25	−122	1.944
28	....	−162	−120	−158	−106	− 60	0	−114	1.945
29	....	−146	− 35	− 16	− 97	− 97	0	− 74	1.932
30	....	− 97	−141	− 14	−130	− 23	− 14	− 76	1.932
31	....	−113	− 23	− 81	− 86	− 7	18	− 56	1.942
Aug. 10	....	....	−141	−198	−160	− 86	− 97	−151	2.009
11	....	−181	−123	− 74	−155	− 60	− 39	−111	1.943
12	....	−104	− 32	− 62	−134	− 93	− 79	− 83	1.879
13	....	−146	− 12	− 74	−212	− 62	− 30	− 95	1.963
14	....	−162	− 65	− 60	− 88	− 93	21	− 88	1.968
15	....	−191	− 76	− 79	−113	− 7	2	− 82	1.942
16	....	−162	− 83	− 58	− 67	− 67	21	− 81	1.936
17	....	− 93	− 62	− 93	− 97	− 7	7	− 65	2.012
18	....	− 25	− 23	− 18	− 90	0	53	− 30	1.920
19	....	−146	−186	−146	−106	− 93	− 53	−131	1.930
20	....	−249	−132	−158	....	−160	−162	−166	1.954
21	−287	−316	−257	−109	−179	− 32	16	−161	1.978
22	0	−292	−193	−127	−134	− 70	− 23	−149	1.945
25	162	−139	....	−179	−162	− 46	53	−124	1.942
27	23	−198	−118	−139	−162	−125	0	−143	1.937
28	....	−167	−228	− 55	−123	− 72	162	−123	2.009
29	....	−118	− 83	− 81	−132	− 51	12	− 89	1.911
30	....	−100	−111	− 81	− 46	− 53	304	− 75	1.937
31	....	−257	−139	− 93	−102	− 70	151	−120	1.947
Sept. 1	....	− 55	−100	5	−120	− 67	9	− 68	1.930
2	0	− 46	−179	− 30	− 18	46	5	− 40	1.911
3	....	−123	− 62	− 46	− 93	− 46	55	− 59	1.911
4	148	− 90	− 70	− 86	− 76	− 42	93	− 69	1.969
5	....	− 46	− 93	0	− 97	18	198	− 40	1.935
6	− 81	−186	− 88	− 30	− 30	− 30	102	− 63	1.921
7	137	− 46	− 79	− 60	− 42	− 44	79	− 54	1.941
8	53	− 53	18	37	− 16	23	18	6	1.958
9	240	0	65	49	0	16	109	27	1.907
10	198	0	0	93	67	127	116	62	1.899
11	....	− 65	− 39	7	− 76	0	35	− 31	1.955
12	....	−132	− 46	− 12	− 7	− 12	93	− 34	1.937
13	....	0	− 39	0	0	0	88	− 8	1.923
14	....	− 70	− 12	0	− 58	− 16	58	− 27	1.924
16	....	74	−162	− 28	− 9	0	−116	− 29	1.969
17	....	−158	− 62	− 53	− 81	− 46	106	− 73	1.934

TABLE 78.—*The daily solar-contrast values, 1916*—Continued.

Date.	Wave lengths in μ. Departures. 0.374	0.426	0.506	0.595	0.607	0.858	1.008	Weighted mean of departures.	Solar constant (calories).
Sept. 18	....	−165	− 97	− 46	−100	− 28	39	− 79	2.035
23	....	− 51	− 32	− 32	− 25	55	160	− 11	1.935
27	....	−113	−170	− 7	− 5	0	16	− 52	1.935
28	....	−111	23	− 70	− 51	− 49	37	− 47	1.929
Oct. 5	....	− 35	....	− 30	....	− 18	....	− 20	1.898
8	....	− 21	− 7	− 18	− 9	23	7	− 4	1.861
14	....	−144	− 67	....	− 37	− 93	60	− 80	1.957
15	....	− 62	− 35	93	0	0	104	3	1.925
16	....	− 74	−104	− 35	−111	42	70	− 50	1.935
17	....	....	− 35	0	−109	....	70	− 48	1.952
18	....	−116	−132	....	70	−137	65	− 78	1.933
19	116	....	− 46	− 46	0	23	0	− 2	1.955
20	− 70	− 46	− 70	104	− 58	− 70	46	− 28	1.969
22	....	−120	74	42	− 60	42	35	5	1.962

TABLE 79.—*The daily solar-contrast values, 1917.*

Date.	Wave lengths in μ. Departures. 0.374	0.426	0.506	0.595	0.607	0.858	1.008	Weighted mean of departures.	Solar constant (calories).
July 1	−268	−257	−100	58	− 90	−111	− 90	− 90	2.034
2	0	−162	−202	− 18	−186	88	− 9	− 82	2.013
3	−116	−193	−123	− 88	−139	−233	65	−155	1.988
4	−167	−275	−113	−104	−172	−100	81	−141	1.995
5	....	− 46	−170	− 93	−162	− 81	14	−112	2.069
6	−198	−198	46	16	− 39	− 46	16	− 34	1.989
7	81	− 76	− 7	− 65	− 90	−125	30	− 74	1.981
8	−233	−139	7	70	−139	−153	0	− 70	1.938
9	....	− 58	− 23	0	....	....	....	− 12	1.921
18	387	−144	162	42	7	46	70	33	1.973
29	−109	−198	− 81	−125	− 62	− 93	21	−105	1.974
30	116	−139	− 46	−120	− 95	− 23	100	− 77	....
Aug. 1	60	− 79	25	− 62	− 42	− 35	65	− 36	2.005
2	93	7	−139	−100	− 30	− 30	186	− 60	2.001
3	−144	−162	− 65	....	−266	....	65	−148	....
4	....	− 93	−151	....	− 88	0	74	− 76	....
5	151	14	− 65	− 51	− 2	− 21	37	− 27	1.971
6	139	−111	7	23	35	2	58	− 2	1.969
7	268	111	−174	− 46	−116	....	58	− 64	1.903
8	0	−198	− 55	83	16	0	55	− 19	1.905
9	0	−174	− 79	− 16	−167	−316	0	−156	....
10	0	−116	− 83	− 14	−125	− 81	0	− 81	....
11	23	− 81	− 60	− 2	−151	− 44	18	− 65	....

TABLE 79.—*The daily solar-contrast values, 1917*—Continued.

Date.	Wave lengths in μ							Weighted mean of departures.	Solar constant (calories).
	0.374	0.426	0.506	0.595	0.607	0.858	1.008		
	Departures.								
Aug. 12	....	....	....	....	− 42	−104	23	− 86	1.929
13	0	− 7	− 62	− 81	....	28	− 32	− 28	1.971
14	93	−268	−104	− 51	− 23	− 49	120	− 85	1.958
15	− 93	− 79	− 51	7	93	30	7	6	....
16	151	−216	− 74	− 46	− 83	−102	23	− 96	1.989
17	125	25	0	− 5	62	12	12	18	1.942
18	93	− 25	−139	7	−102	− 55	16	− 64	1.988
19	257	0	0	116	0	0	18	23	1.924
20	447	44	− 32	− 42	− 67	− 23	106	− 28	1.956
21	46	46	− 39	−120	− 53	− 30	0	− 44	1.927
22	158	− 81	− 53	−170	18	7	42	− 51	1.960
26	0	− 18	− 12	− 37	93	− 32	65	− 4	1.934
27	23	− 53	−123	5	− 70	12	74	− 42	1.955
28	162	51	− 60	65	32	18	79	19	1.966
29	76	60	7	0	− 46	118	0	30	1.965
31	198	− 32	− 16	− 7	0	0	− 16	− 9	1.952
Sept. 1	304	−162	− 7	14	0	97	5	3	1.960
2	0	70	0	12	− 5	0	127	11	1.921
3	268	35	− 25	162	− 83	51	233	29	1.989
7	− 62	−139	−132	74	− 37	− 9	9	− 41	1.956
8	186	− 35	− 90	− 7	−102	46	195	− 33	1.948
9	233	− 55	−100	− 32	− 12	− 16	186	− 41	1.981
11	−162	−137	− 42	− 12	−139	7	74	− 56	1.984
12	− 51	− 60	−106	0	− 72	− 37	111	− 53	1.940
13	− 81	−257	−167	−123	−151	− 23	0	−130	1.942
14	23	−228	−151	37	−127	−127	0	−111	1.979
15	0	−158	−104	−151	−104	− 79	0	−114	1.967
16	0	−179	− 23	−162	−109	− 53	28	97	1.952
17	....	−127	−116	− 55	−153	− 51	53	− 95	1.946
18	−139	−139	− 65	− 81	− 46	0	18	− 58	1.963
19	363	− 81	− 39	− 49	− 18	81	− 7	− 12	1.940
20	−116	−257	− 46	− 51	− 46	− 58	116	− 79	1.905
22	0	−249	70	− 70	− 37	−162	62	− 82	1.962
24	....	−205	−186	− 23	−100	51	58	− 78	1.889
25	− 70	− 46	− 35	14	7	− 7	139	− 11	1.948
26	411	−139	− 53	− 12	0	− 60	51	− 47	1.946
27	139	−123	−139	− 46	0	− 86	35	− 76	1.934
30	139	− 21	0	0	− 23	0	88	− 8	1.900
Oct. 1	104	− 88	− 83	7	−186	0	35	− 62	1.951
2	83	−172	− 72	−104	−153	−144	55	−125	1.949
3	−170	−205	104	− 67	− 67	− 53	130	− 35	1.903
6	198	− 97	46	23	− 16	0	49	− 3	1.942
7	−280	−214	− 37	− 74	−130	− 42	125	− 89	1.937
8	− 51	−195	− 44	− 74	− 83	− 93	12	− 91	1.915
9	−186	−226	−137	−104	− 46	− 39	58	− 99	2.062

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TABLE 80.—*The daily solar-contrast values, 1918.*

Date.	Wave lengths in μ. 0.374	0.426	0.506	0.595	0.607	0.858	1.008	Weighted mean of departures.	Solar constant. Weight 2, Calama, corresponding 3 hours.	Weight 1, Mount Wilson.	Weighted mean.
	Departures.										
June 24	− 30	−104	− 70	− 60	− 12	....	0	− 54	....	1.892	1.892
25	0	−123	−127	25	− 37	− 37	0	− 54	....	1.943	1.943
26	257	−280	0	93	21	53	134	− 3	....	1.918	1.918
29	− 58	174	....	....	−116	70	28	31	....	1.943	1.943
July 3	0	−144	−144	0	− 70	− 9	0	− 65	....	1.934	1.934
4	186	−228	−174	− 32	− 65	− 65	−170	−102	....	1.935	1.935
5	198	−233	− 16	−37	− 67	18	144	− 52	....	1.969	1.969
6	30	− 88	− 67	16	− 95	30	14	− 35	....	1.957	1.957
8	−174	−328	7	−116	− 62	− 21	21	− 85	....	1.980	1.980
9	1	− 12	−102	− 18	− 25	− 79	51	− 50	....	2.022	2.022
14	35	− 23	− 58	− 46	− 46	− 70	95	− 51	....	1.971	1.971
15	− 25	−287	− 53	− 39	−111	− 28	39	− 88	....	1.942	1.942
16	23	− 5	− 42	7	− 21	− 9	53	− 14	....	....	....
20	−641	−268	− 46	−146	−116	−158	127	−139	....	....	....
21	0	− 30	−228	−111	−174	−139	0	−142	....	1.938	1.938
22	0	− 93	− 62	−158	− 28	− 86	58	− 84	....	1.929	1.929
23	97	0	− 35	0	− 21	− 28	97	− 18	....	1.920	1.920
24	28	....	0	9	− 53	− 7	111	− 13	....	1.916	1.916
25	....	0	− 35	12	− 46	14	0	− 10	....	1.968	1.968
26	292	− 18	− 23	− 12	− 12	51	83	0	....	1.958	1.958
27	23	− 35	− 30	46	− 76	42	12	− 7	1.939	1.949	1.942
28	352	0	− 16	− 23	− 35	5	12	− 13	1.901	1.947	1.916
29	238	− 58	− 42	97	−162	70	162	− 12	1.899	1.908	1.902
Aug. 2	104	−120	−186	− 67	−139	0	49	− 95	....	1.885	1.885
3	556	−328	− 81	0	−102	18	70	− 78	1.963	1.946	1.957
4	280	− 12	− 76	−100	− 7	0	81	− 38	1.949	1.956	1.951
5	....	− 18	0	7	−116	0	35	− 24	1.956	1.953	1.955
8	0	....	0	14	−104	0	0	− 22	1.955	1.936	1.949
9	0	− 35	− 81	− 49	−116	− 23	62	− 60	....	1.946	1.946
10	0	−134	0	− 55	− 90	− 30	70	− 55	1.955	1.962	1.957
11	− 18	5	12	0	− 23	0	58	− 1	1.964	1.938	1.955
12	93	202	− 14	0	− 35	0	49	19	1.955	2.008	1.969
13	186	0	−146	0	−162	0	0	− 61	....	1.938	1.938
14	0	−116	−139	− 46	− 2	−116	2	− 83	1.928	1.948	1.935
18	....	....	− 88	− 18	−226	−134	37	−125	....	....	....
19	177	− 83	− 7	− 51	−104	− 23	37	− 50	1.947	1.942	1.946
20	181	− 25	− 28	0	− 2	0	90	− 9	1.947	1.938	1.944
21	0	− 23	44	− 46	55	18	35	12	1.990	1.971	1.984
22	0	0	− 23	70	0	0	0	10	1.956	1.949	1.954
23	23	− 7	0	9	− 32	0	167	− 5	1.973	1.957	1.968
28	− 23	− 16	−165	−134	−113	− 93	− 16	−108	1.901	....	1.901
29	0	− 35	− 46	− 9	7	2	104	− 14	1.954	1.929	1.946
Sept. 1	292	− 65	− 23	− 79	− 65	93	109	− 19	1.980	1.979	1.980
2	252	−106	− 46	− 49	− 70	37	139	− 39	....	1.921	1.921

TABLE 80.—*The daily solar-contrast values, 1918*—Continued.

Date.		Wave lengths in μ.							Weighted mean of departures.	Solar constant.		
		0.374	0.426	0.506	0.595	0.607	0.858	1.008		Weight 2, Calama, corresponding 3 hours.	Weight 1, Mount Wilson.	Weighted mean.
		Departures.										
Sept.	5	− 46	−139	−148	− 5	− 58	− 14	12	− 65	....	1.951	1.951
	6	198	− 32	....	− 12	− 12	16	....	− 5	1.939	1.962	1.947
	9	....	− 93	−134	− 88	− 32	0	− 42	− 64	1.931	1.862	1.908
	16	216	− 86	−127	42	− 12	30	− 30	− 24	1.943	1.997	1.962
	18	268	− 95	0	− 35	− 74	0	102	− 35	1.958	....	1.958
	19	488	− 25	− 21	− 7	0	0	102	− 9	1.943	1.991	1.969
	20	16	− 35	−170	− 12	− 5	0	0	− 42	....	1.956	1.956
	24	0	− 93	− 70	51	− 70	0	62	− 31	....	1.944	1.944
	25	....	−193	....	− 23	....	− 12	....	− 58	....	2.025	2.025
Oct.	9	198	....	0	....	− 53	....	155	− 26	1.942	1.950	1.945
	10	0	− 90	7	− 28	− 42	− 12	− 12	− 28	1.940	1.966	1.948
	11	0	− 5	− 18	− 18	− 9	0	53	− 10	1.865	1.993	1.908
	12	0	0	− 23	− 62	− 21	− 23	49	− 27	....	1.995	1.995
	13	544	− 12	32	0	− 88	151	0	25	1.901	....	1.901

TABLE 81.—*The daily solar-contrast values, 1919.*

Date.		Wave lengths in μ.							Weighted mean of departures.	Solar constant.		
		0.374	0.426	0.506	0.595	0.607	0.858	1.008		Weight 2, Calama, corresponding 3 hours.	Weight 1, Mount Wilson.	Weighted mean.
		Departures.										
June	16	93	− 44	−151	−198	−209	− 60	− 37	−133	1.927	1.953	1.936
	17	351	−268	− 76	−209	−216	− 9	18	−140	....	2.016	2.016
	18	70	− 37	−146	−162	−162	....	0	−124	....	1.987	1.987
	21	765	104	−158	−120	−132	− 46	151	79	2.006	1.999	2.005
	22	864	− 23	23	− 35	− 69	23	....	− 14	1.962	1.959	1.961
	23	864	− 32	− 21	− 30	− 14	−174	−100	− 22	1.972	1.934	1.960
	24	495	23	−106	−116	− 23	12	− 86	− 43	1.952	1.944	1.949
	25	666	− 37	−109	− 55	−177	− 83	−106	− 94	1.951	1.944	1.949
	26	351	−257	−366	−109	−151	−212	−186	−214	1.927	1.929	1.928
	28	46	−304	− 60	− 70	−177	− 93	− 7	−127	1.967	1.969	1.968
	29	198	−340	− 18	−186	−177	−195	−104	−173	1.968	1.974	1.970
	30	292	−209	−104	−132	−280	−144	−186	−168	1.959	1.963	1.960
July	1	304	−209	−193	−228	−335	−221	−198	−256	1.940	1.961	1.947
	2	83	−268	−280	− 58	−106	....	−146	−158	1.925	1.912	1.921
	3	1,118	−209	−209	−209	−292	−132	−120	−204	1.934	1.969	1.946
	6	209	−233	−198	−304	−116	−174	− 23	−200	1.971	1.951	1.964
	9	86	−127	− 42	−102	....	....	....	− 77	1.954	1.993	1.970
	10	− 81	− 81	0	− 7	− 42	−134	−174	− 55	1.958	1.946	1.954
	11	642	21	−532	....	−139	− 70	−104	−186	1.951	1.945	1.949
	13	....	−106	....	−174	....	−127	....	−166	1.944	....	1.944
	14	690	....	−209	− 49	−139	− 70	−102	−121	1.964	1.964	1.964

TABLE 81.—*The daily solar-contrast values, 1919*—Continued.

Date.		Wave lengths in μ.							Weighted mean of departures.	Solar constant.		
		0.374	0.426	0.506	0.595	0.607	0.858	1.008		Weight 2, Calama, corresponding 3 hours.	Weight 1, Mount Wilson.	Weighted mean.
		Departures.										
July	20	....	− 97	....	− 60	....	−221	....	− 64	1.961	[1] 1.805	1.961
	21	228	−139	−137	− 97	−148	−170	− 9	−138	1.959	1.996	1.971
	22	221	− 60	− 90	− 93	− 90	−280	12	− 79	1.971	1.943	1.962
	23	....	− 76	−193	− 23	−153	−146	....	−176	1.965	1.952	1.961
	24	....	....	−148	−139	−155	− 9	−162	−110	1.957	1.945	1.953
	27	....	139	−118	− 16	−148	−249	−172	− 99	1.929	1.984	1.947
	29	226	−247	−181	−287	−177	−139	−167	−198	1.956	1.985	1.964
	30	....	− 70	− 37	− 74	− 97	− 55	72	− 54	1.935	1.949	1.940
	31	70	198	− 30	−155	− 81	−109	− 28	− 53	1.934	1.925	1.931
Aug.	1	181	58	−162	−139	−177	− 90	46	−148	1.957	1.961	1.958
	2	435	− 72	− 67	−123	− 83	25	0	− 58	1.948	1.934	1.943
	3	411	− 93	−193	− 49	− 60	−155	− 53	−112	1.977	1.958	1.971
	4	508	− 2	−268	....	−179	−116	− 42	−148	1.960	1.950	1.957
	5	478	5	−238	− 46	−233	−123	− 60	−133	1.961	1.962	1.961
	6	....	− 35	−111	....	....	....	....	− 67	1.944	....	1.944
	7	179	88	−146	−106	−100	−102	0	− 84	1.962	1.896	1.940
	10	186	30	12	−116	−170	−127	0	− 82	1.957	1.958	1.957
	12	....	....	− 23	− 14	− 58	....	....	− 32	....	1.922	1.922
	13	532	214	−144	− 49	−109	− 62	− 58	− 46	1.927	1.921	1.925
	14	401	70	− 55	144	12	− 79	− 65	− 35	1.946	1.946	1.946
	19	93	−233	−281	−268	−252	− 79	− 93	−213	1.929	1.924	1.927
	22	368	28	−209	− 49	− 49	− 74	− 58	− 76	1.965	1.927	1.952
	23	328	221	− 88	....	− 51	− 70	....	− 18	1.961	1.987	1.970
	27	617	100	−109	− 9	− 65	139	−118	42	1.954	....	1.954
	28	351	152	−155	− 79	− 88	− 79	− 49	− 63	1.958	1.944	1.953
	29	359	228	−193	−170	− 53	− 55	− 88	− 65	1.963	1.961	1.962
	30	280	252	−198	18	−116	− 67	79	− 41	1.950	1.952	1.951
Sept.	1	46	76	−162	− 35	−100	− 97	....	− 73	1.935	1.951	1.940
	2	593	30	−111	− 42	− 35	− 23	− 12	− 39	1.918	1.921	1.919
	3	411	− 28	−238	−191	58	−104	− 76	−104	1.932	1.951	1.938
	4	666	−139	−127	− 86	−100	−238	− 97	−102	1.945	1.937	1.942
	5	399	−109	− 69	− 42	− 32	− 74	− 32	− 62	1.939	1.933	1.937
	6	....	116	−118	− 93	−137	− 93	79	− 84	1.945	1.936	1.942
	7	....	256	−109	70	−141	−127	−111	− 32	1.943	1.934	1.940
	8	70	35	−139	− 70	−179	5	37	− 72	1.953	1.942	1.949
	11	352	58	0	− 23	− 25	− 28	− 28	− 8	1.944	1.975	1.954
	12	93	23	23	−148	−162	− 28	− 32	− 61	1.922	1.941	1.928
	13	....	0	− 46	− 74	−125	....	− 35	− 61	1.953	1.957	1.954
	16	864	186	− 21	− 35	− 62	− 30	0	− 5	....	1.967	1.967
	17	−592	− 16	−104	− 21	− 67	− 76	− 28	− 60	1.934	1.936	1.935
	18	592	97	−130	− 14	− 81	− 86	32	− 53	1.949	1.885	1.931
	19	....	42	− 2	35	− 2	58	35	26	1.957	1.965	1.960
	20	592	155	− 25	58	− 49	−116	16	− 11	1.953	1.959	1.955

[1] This value is omitted in the mean.

TABLE 82.—*The daily solar-contrast values, 1920.*

Date.	Wave lengths in μ.							Weighted mean of departures.	Solar constant.		
	0.374	0.426	0.506	0.595	0.607	0.858	1.008		Weight 2, Calama, corresponding 3 hours.	Weight 1, Mount Wilson.	Weighted mean.
	Departures.										
July 9	....	−106	0	58	23	0	....	1	1.942	1.942	1.942
10	....	− 23	− 46	12	0	18	....	− 5	1.934	1.937	1.935
11	....	−132	− 32	− 46	−123	− 58	....	− 73	1.945	1.932	1.941
12	....	− 46	46	21	− 55	− 62	....	− 19	1.944	1.949	1.946
13	....	....	− 37	− 65	− 97	−100	....	− 76	....	1.927	1.927
14	....	−216	− 90	−123	−130	− 65	....	−116	....	1.899	1.899
17	....	− 65	74	70	116	111	....	71	....	1.934	1.934
18	....	0	116	0	....	0	....	29	1.933	1.919	1.928
19	....	0	− 12	−100	0	0	....	− 22	1.934	1.927	1.932
20	....	− 35	−130	37	0	− 28	....	30	1.950	1.931	1.944
21	....	− 88	7	97	−111	− 23	....	− 19	1.963	[1] 1.856	1.963
24	....	− 70	21	0	− 35	− 28	....	− 19	1.949	1.932	1.943
25	....	....	− 81	0	− 97	−116	....	− 76	1.944	1.918	1.935
26	....	−127	− 28	−116	− 93	− 62	....	− 81	1.950	1.958	1.953
28	....	37	0	0	− 23	− 51	....	− 12	....	1.912	1.912
29	....	70	−123	0	− 60	53	....	− 13	....	1.924	1.924
Aug. 3	....	0	42	− 42	0	30	....	78	1.919	[1] 2.090	1.919
4	....	198	− 12	83	16	23	....	51	1.923	1.926	1.924
5	....	158	53	123	0	116	....	87	1.931	1.921	1.928
7	....	55	120	30	0	28	....	45	1.931	1.945	1.936
8	....	81	18	93	14	18	....	41	1.924	1.912	1.920
9	....	− 30	− 30	7	32	− 23	....	− 8	1.935	1.924	1.931
12	....	−127	− 81	− 81	−127	− 42	....	− 86	1.938	1.951	1.942
13	....	− 97	−109	− 72	−120	39	....	− 64	1.972	1.968	1.971
14	....	−193	−127	− 81	− 93	− 72	....	−106	1.921	1.922	1.921
15	....	−233	−177	− 86	−245	−162	....	−176	1.920	1.903	1.914
16	....	−186	−111	− 93	− 70	− 23	....	− 87	....	1.970	1.970
18	....	−181	−111	−102	−109	− 67	....	−107	1.943	1.937	1.941
19	....	− 93	− 83	− 37	−198	−288	....	−150	1.938	1.922	1.933
20	....	− 42	− 81	0	− 53	− 39	....	− 42	1.926	1.976	1.943
21	....	− 51	− 60	− 42	−195	− 28	....	− 74	1.941	1.935	1.939
22	....	−174	−214	− 35	0	−162	....	−115	1.945	1.990	1.960
27	....	−144	− 97	− 51	−111	− 28	....	− 79	1.931	1.912	1.925
29	....	−221	−186	− 93	−174	− 46	....	−134	1.916	1.915	1.916
30	....	−139	− 97	0	−144	− 90	....	− 90	1.921	1.994	1.945
Sept. 2	....	− 46	−181	−158	−123	−172	....	−143	1.955	1.912	1.941
3	....	−179	−174	−137	−141	−174	....	−160	1.952	1.917	1.940
4	....	−179	−179	−132	−106	− 86	....	−131	....	1.923	1.923
5	....	−144	−179	− 86	−102	−137	....	−129	1.930	1.920	1.927

[1] Omitted in mean.

DISCUSSION OF THE DAY-TO-DAY DRIFT-CURVE RESULTS.

Götz [10] has raised the point that the apparent distribution of radiation along the diameter of the sun's disk must be affected by the degree of transparency of the air. He has worked up this objection somewhat elaborately, but the point may be clearly understood by the reader if he reflects that on a very hazy day when the position of the sun in the sky is but just noticeable there must apparently be a great deal less contrast between the center and limb of the sun than if the sky is very clear so that the solar disk is sharply defined. We must admit, then, the sense of the objection qualitatively, and we have to investigate whether quantitatively its effect is considerable.

Taking, respectively, the high, medium, and low slant numbers given in Table 73, we have changed some of the days to bring in those for which proper spectrobolometric determinations of the transparency of the air were available, but have still retained the grouping of high, medium, and low slant numbers as before. For each of the days selected, which include the years 1915 to 1920, we have taken the atmospheric transmission coefficients determined at wave lengths 0.35, 0.40, 0.45, and 0.50μ. We have then determined the mean transmission coefficients at each of these selected wave lengths for each of the groups of 5 days, and also the general mean for all the high, all the medium, and all the low days, including for the high group 25, for the medium group 30, and for the low group 24 days of observation. These data are assembled in the following Table 83, from which it appears that the individual years of observation show slight variations of atmospheric transparency, now in one direction, now in the other, and that the general mean of all appears to indicate a slightly greater transmissibility for the high and medium groups than for the low group. This tendency in the general mean is in the opposite direction to that which would be expected on the basis of Götz's objection. For, as we have stated, days when the slant numbers are low are days of greater solar contrast, so that we find that the days of greatest solar contrast occurred when the transparency of the air was the least in the three groups of days selected. The differences, however, are very small, and we attribute them wholly to the inadequate number of days to eliminate entirely from the mean wide variations of transparency from day to day. We see no reason to believe that the effect of variations in the haziness of the atmosphere at Mount Wilson has influenced appreciably our results on the distribution of radiation over the sun's disk.

[10] Astronomische Nachrichten, Nr. 5093, Bd. 213, March, 1921.

Table 83.—*Influence of atmospheric transparency on apparent solar contrast.*

High.					Medium.					Low.				
Date.	μ 0.35	μ 0.40	μ 0.45	μ 0.50	Date.	μ 0.35	μ 0.40	μ 0.45	μ 0.50	Date.	μ 0.35	μ 0.40	μ 0.45	μ 0.50
1915.					1915.					1915.				
Oct. 8	537	700	802	861	Oct. 11	607	745	830	877	July 12	610	740	816	867
Sept. 27	611	745	821	870	July 3	590	728	817	870	Aug. 11	548	692	776	832
28	593	736	816	876	14	570	723	817	867	June 10	580	726	821	878
Oct. 16	568	719	805	865	Aug. 17	617	756	837	880	Aug. 20	584	728	804	854
Aug. 25	603	732	821	875	24	582	721	805	860	June 27	565	695	780	820
Means..	582	726	813	869	Means.	593	735	821	871	Means.	577	716	799	850
1916.					1916.					1916.				
Sept. 8	587	714	790	840	July 5	604	756	840	878	Aug. 19	595	722	802	858
9	620	738	815	867	6	583	736	819	871	20	591	721	802	853
10	605	726	799	848	7	616	743	821	867	21	587	700	783	830
11	596	711	789	843	8	602	747	826	884	22	592	710	784	825
12	600	712	800	844	9	630	750	826	881	27	574	700	782	837
Means.	602	720	799	848	Means.	607	746	826	876	Means.	588	711	791	841
					Aug. 29	616	738	821	863					
					30	617	729	788	834					
					Sept. 1	585	734	821	869					
					3	580	681	741	786					
					4	598	698	762	801					
					Means.	598	716	787	831					
1917.					1917.					1917.				
July 18	555	684	758	815	Aug. 2	544	685	780	828	July 3	432	581	680	746
Aug. 28	635	754	829	875	14	457	586	665	720	4	495	639	730	788
29	627	748	826	875	Sept. 20	561	693	767	813	5	560	700	790	838
30	625	745	825	869	22	590	730	815	860	Oct. 2	547	702	794	852
Sept. 3	602	703	767	816	24	597	735	820	865	Sept. 13	639	756	825	860
Means.	609	727	801	850	Means.	550	686	769	817	Means.	535	676	764	817
1918.					1918.					1918.				
June 29	530	653	733	792	July 5	586	717	807	863	July 4	582	698	783	840
July 25	550	689	785	855	14	560	710	795	850	8	540	669	745	799
27	608	735	815	867	Aug. 9	576	718	800	(855)	21	578	731	826	850
Aug. 21	592	723	812	859	10	582	711	786	843	Aug. 2	605	725	806	853
22	582	732	816	870	13	569	696	781	836					
Means.	572	706	792	849	Means.	575	710	794	849	Means.	576	706	790	835
1919.					1919.					1919.				
June 21	649	734	795	831	June 18	614	733	807	848	June 26	612	710	776	825
Sept. 11	660	754	818	857	28	631	744	830	885	July 1	688	772	835	874
16	632	728	797	845	July 14	......	704	772	820	3	602	730	805	850
19	617	708	770	813	24	603	698	762	807	6	628	742	810	857
20	604	703	770	822	Aug. 3	650	750	817	855	Aug. 19	616	719	798	850
Means.	632	725	790	834	Means.	624	726	798	843	Means.	629	735	805	851

TABLE 83.—*Influence of atmospheric transparency on apparent solar contrast*—Continued.

High.					Medium.					Low.				
Date.	μ 0.35	μ 0.40	μ 0.45	μ 0.50	Date.	μ 0.35	μ 0.40	μ 0.45	μ 0.50	Date.	μ 0.35	μ 0.40	μ 0.45	μ 0.50
1920.					1920.					1920.				
July 17	643	737	807	878	July 19	622	755	834	887	Aug. 15	594	......	680	776
Aug. 3	501	574	711	768	21	621	725	815	862	19	622	788	839	876
4	598	707	824	843	Aug. 13	544	627	720	770	Sept. 2	588	705	782	812
5	638	745	840	873	20	635	714	815	865	3	521	608	705	753
7	608	734	810	861	21	638	744	804	871	4	605	744	792	845
Means.	598	699	798	845	Means.	612	713	796	851	Means.	586	711	760	812
Mean of all.	599	717	799	849	Mean of all.	594	719	799	848	Mean of all.	582	709	785	834

The sun is not devoid of local surface features. Sun spots, often accompanied by faculæ, are apt to be located somewhere on the east and west solar diameter. It is rare, to be sure, that a sun spot falls exactly on the solar equator, as was the case on or about March 20, 1920. But the solar equator seldom coincides with the east and west diameter, so that spot groups situated some distance from the equator are apt to be encountered in our drift work, and especially toward the sun's limb. Wherever such a sun-spot group or group of faculæ is observed, a certain irregularity of the drift curves results. Thus, as it is to be expected, many of the drift curves are irregular, and the logarithmic slant curves are often far from indicating straight lines. In such cases the judgment of the observer plays an arbitrary part in deciding how to assign the slant numbers and the contrast number for the day.

In illustration of several varieties of slant curves observed, we give figure 35. The east and west halves of the sun's disk have been kept separated in these figures, and the curves represent departures from the mean results of the year 1913 as obtained from several consecutive drifts across the solar image. The reader may readily see that the curves of the several wave lengths support each other in showing certain spots of greater and less intensity, as definitely located on one or the other side of the solar disk at definite distances from the center.

Notwithstanding these irregularities it is easy to see that, for instance, the curves of August 9 indicate equal or less contrast and those of September 4 greater contrast than the standard mean form of 1913.

Coming next to the question of correlation between day-to-day solar-constant and solar-contrast values, it has been pointed out already that for the year 1913 increased contrast accompanied decreased solar-constant values, and so consistently that the correlation coefficient is

$$r = +0.601 \pm 0.067.$$

No other years show such a high positive correlation, though in 1914, 1918, and less distinctly in one or two others, there is a correlation in the same sense.

On the other hand the year 1916 has a long period from August 10 to September 18, when the correlation coefficient is

$$r = -0.363 \pm 0.097.$$

Other periods of negative correlation occur. In some years there appears to be a fluctuating day-to-day correlation, now positive, now negative.

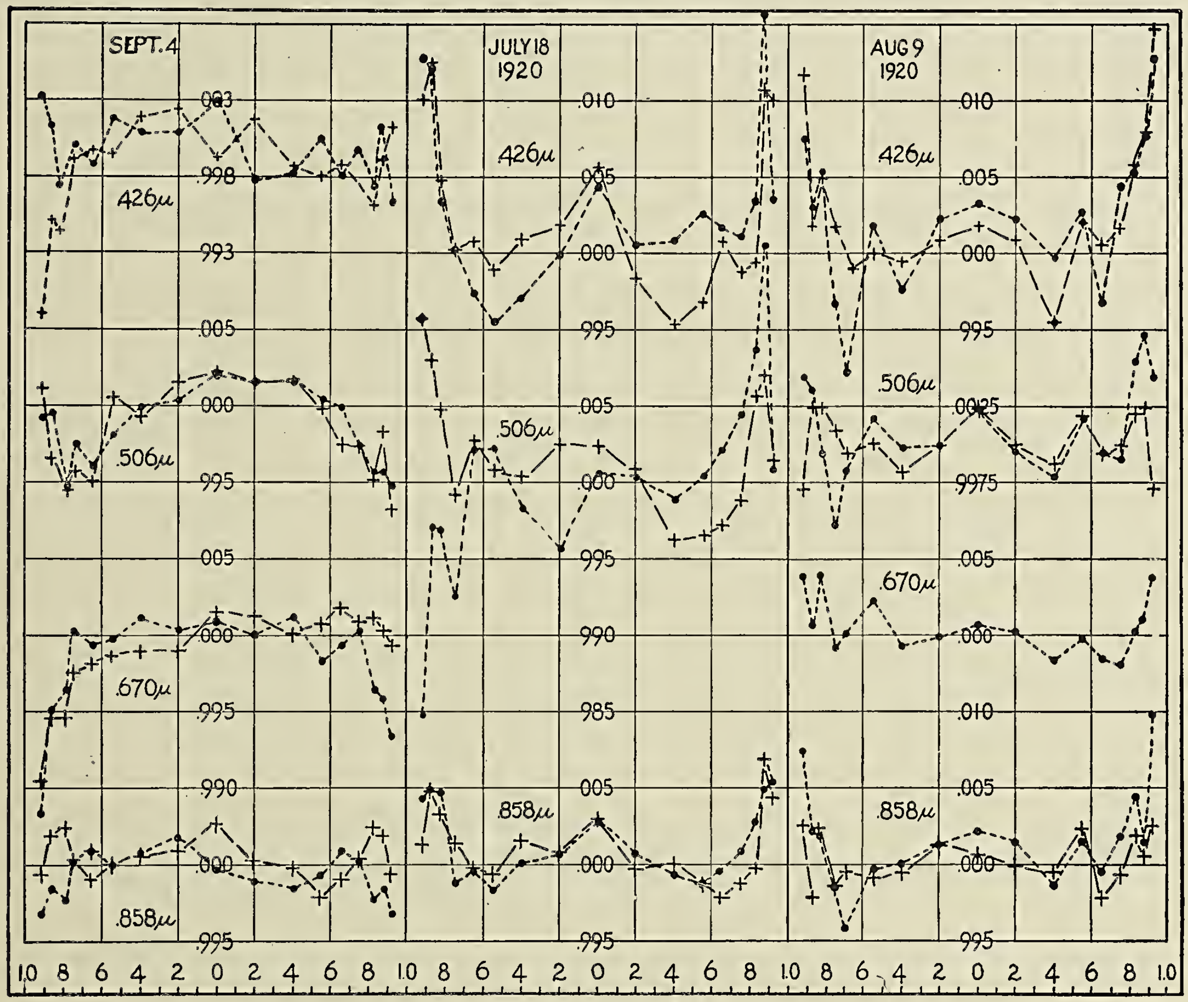

Fig. 35.—Typical cases of solar distribution curves.

We have already pointed out similar cases of fluctuating day-to-day correlations between the solar constant and other phenomena. This is shown at a preceding page with respect to sun spots. Mr. Clayton discovers it with respect to terrestrial temperatures. Though perplexing, we feel more and more convinced by longer study that these fluctuations of correlation and occasional absences of correlation are not to be regarded as evidences of accidental error of the solar-constant values, but are rather due to combinations of conflicting influences.

In the case of solar contrast versus solar constant, we suggest a threefold hypothesis of the nature of solar variation. It is as follows:

Cause A: Variation in solar activity varies the rate of upheaval of fresh radiating surfaces and so alters the sun's effective temperatures.

Effect A: Increased solar radiation attends increased solar contrast. For if the solar radiation were zero, the solar contrast would be zero also.

Cause B: Variation occurs in the transparency of the outer solar envelopes.

Effect B: Increased solar radiation attends decreased contrast. For if the transparency increases, its increase produces most effect at the solar limb where the depth of the layer in question is increased by obliquity of the line of sight.

Cause C: Solar rotation brings into the beam columns of more or less transmissibility.

Effect C: Increased solar radiation attends increased pseudocontrast. For if the column of increased transparency points roughly toward the earth at a given time, it is most apt to arise from (roughly speaking) the center of the solar disk. Hence this central part of the disk appears brighter relative to the limbs.

If these suggestions are admitted, it is obvious that combinations of A or C with B may produce conflicting results according to which of the causes is in predominance.

With these remarks we leave the subject to the attention of the reader.

THE DISTRIBUTION OF RADIATION ALONG THE NORTH AND SOUTH DIAMETER OF THE SOLAR IMAGE.

Investigation by the method of stopping the coelostat clock being limited as we have said to the study of distribution along the east and west diameter of the solar image, we desired to arrange apparatus so that we might also investigate the distribution at right angles to this, and possibly at other angles also, to see if the solar image is symmetrical along all diameters in the distribution of its radiation. For this purpose it was necessary either to move the bolometric apparatus with reference to a fixed image, or to move the image with reference to the bolometric apparatus. We chose the latter device. In order to accomplish it, we ordered in 1915 from William Gaertner & Co. a special contrivance of mounting for the second mirror of the coelostat on the tower, and certain mechanism by means of which this mirror could be given slow rotation either about a north and south or an east and west horizontal axis. Thus the solar image, being kept in a fixed position as regards diurnal motion by the uniform motion of the first mirror of the coelostat would in addition be given one or a combination of two drifts by the additional motions imparted to the second mirror of the coelostat. In this way the drift of the image could be produced either directly north and south or at any angle thereto according to the relative values of the two motions imparted to the second mirror of the coelostat. We proposed to impart these motions to the two axes by connecting their mechanisms to the coelostat clock. In addition we introduced disconnecting and adjusting devices which could be operated by the observer at the bottom of the tower, so that the motions could be imparted by the clock or by hand as desired. These requirements were accomplished by the apparatus which was constructed by William Gaertner & Co. and installed on Mount Wilson.

The apparatus was adjusted and tested by Mr. Aldrich in 1918 and after a few trials he found it possible to move the solar image in a north and south direction very gradually and uniformly.

One other device was necessary, however, in order to complete the arrangement. The slit of the spectrobolometer is of course vertical and in the ordinary use of the instruments for the drift work in the east and west direction, the portion of the solar image at the moment under investigation is reflected horizontally toward the north so as to enter the spectrobolometer slit in exactly the same manner as the solar beam from the coelostat south of the observatory when we carry on solar-constant work. Thus when the coelostat clock is stopped, in our ordinary drift work investigations, the solar image drifts east and west across the slit just as we would desire it to do. Now it is clear that if the beam does not drift east and west, but does drift north and south under the influence of the new motion imparted to the second mirror of the coelostat, then if we should use only the same arrangements as before, the drift would be vertical, along the slit of the spectrobolometer, instead of across it as we desire. In order to produce cross drift another small mirror was introduced in addition to the 45° mirror which ordinarily reflects the beam to the north. In this way it was possible to cause the north and south drift of the solar image to be transformed into an east and west drift where the beam crossed the spectrobolometer slit. When drifts were produced in still other directions, neither east and west nor north and south but a combination of the two, the auxiliary little mirror could be set at another angle so as still to transform this combination drift into a motion across the slit as desired.

OBSERVATIONS.

At Mount Wilson, on July 15, July 26, August 28, and September 5, 1918, Mr. Aldrich made observations of the radiation over the sun's disk at various wave lengths, both by the ordinary method of east and west drift and by the use of the above-mentioned apparatus for north and south drift. The results of the work were very satisfactory and indicate no appreciable difference between the distributions of radiation east and west and north and south. On this account the investigation was not continued to embrace drifts in other directions.

In the reduction of the observations it was of course impossible to compute the proper width corresponding to the total diameter of the sun by the aid of the ephemeris, as is done in the reduction of the east and west drifts.[11] In order to fix upon the most suitable value for this width, Mr. Fowle measured a considerable number of the east and west drift curves and found at what proportion of the central height of the curve a horizontal line parallel to the axis of zero radiation would intercept the drift curve at points whose distance apart corresponded with the computed width of the sun by the ephemeris. This height proved to be 21.7 per cent. Widths of this height agreed with widths determined by Mr. Aldrich by observing and electrically recording transits of the sun's limbs within 0.2 per cent.

Taking, on each of the north and south drift curves, the distance corresponding to the position just defined as that representing the diameter of the solar disk, Mr. Fowle measured at fractions of this width corresponding to 0.2, 0.4, 0.55, and the other usual positions out upon the solar radius the ordinates of the drift curves. These results were then reduced in exactly the same way which is employed with the east and west drift curves, and which has been explained in these Annals, Volume III, page 155.

Employing the auxiliary standard reduction values of 1913, he then determined the departures of the east and west and north and south drift curves of the dates mentioned above from the standard forms. In order to obtain for each day's observation a single value which would be typical of the departure of each wave length from the standard form, he plotted the departures logarithmically as ordinates against distances out on the solar radius as abscissæ and produced the best representative straight lines corresponding to the plots to the abscissæ corresponding to 100 per cent out on the solar radius. This is precisely the same procedure which is described under the caption "Changes of Distribution from Day to Day" at a former page.

There resulted departures at the edge of the sun from the standard values of 1913 comparable with those published in the preceding Tables 75 to 82. These departures, however, we reduced to percentages so as more directly to indicate the magnitude of the differences between the north and south and the east and west drifts. The results of the comparison are given in the following Table 84.

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[11] See Annals III, 154.

TABLE 84.—*Results of comparison of N.-S. with E.-W. solar drift curves.*

[Percentage departures at edge of sun from standard value of 1913.]

Date.	Wave lengths.						Direction of drift.	Weighted mean.	E.-W. minus N.-S.
	0.4265μ.	0.5062μ.	0.5955μ.	0.6702μ.	0.8580μ.	1.008μ.			
1918.								*Per cent.*	*Per cent.*
July 15	−2.87 g.	−0.53 p.	−0.39 g.	−1.11 g.	−0.28 g.	+0.39 g.	E.-W.	−0.60	+0.41
	−3.94 g.	−0.95 p.	−0.69 g.	−1.98 g.	−0.32 p.	+0.37 g.+	N.-S.	−1.01	
July 26	−0.18 p.	−0.23 v. g.	−0.12 e.	−0.12 v. g.	+0.51 p.	+0.83 v. g.	E.-W.	+0.28	+0.79
	−0.42 p.	−0.46 v. g.	−0.18 e.	−1.53 e.	−0.90 e.	+0.25 v. g.	N.-S.	−0.51	
Aug. 28	−0.16 g.	−1.65 v. g.	−1.34 g.	−1.13 e.	−0.93 g.	−0.16 g.	E.-W.	−0.95	−0.42
	−0.14 g.	−0.16 v. p.	−0.35 g.	−0.46 g.	−0.58 g.−	−0.69 p.	N.-S.	−0.53	
Sept. 5	−1.39 v. g.	−1.48 v. g.−	−0.05 v. g.	−0.58 v. g.	−0.14 g.	+0.12 e.	E.-W.	−0.50	−0.14
	−1.27 g.	−1.16 g.	+0.14 p.	−0.07 v. g.+	−0.25 v. g.−	+0.05 v. g.	N.-S.	−0.36	

The first of each pair is for the standard direction, E.-W., the second, N.-S. The letters e., v. g., g., and p. signify excellent, very good, good, and poor observations, as indicated by their irregularity with respect to a smooth representative line.

The weighted mean values differ from those of Table 80 because the values for wave length 1.008μ, there excluded, are here included in the mean.

From the table which has just been given, it appears that the differences between the north and south and the east and west drifts are small for all wave lengths and perhaps entirely within the experimental error of the determination. The several days disagree one with another in the sign of the departure as shown by the final mean results given in the concluding column of the table, so that the average deviation taken with regard to sign is almost zero. From this we conclude that the differences, if any, between the distribution of radiation along the east and west and the north and south diameters of the sun on these occasions were too small to be determinable by our means of observation.

It is to be remembered that the investigation of the north and south drift can never be of the same order of relative accuracy from day to day as the investigation of the east and west drift, for in the latter case the telescope points to a fixed position in the sky and observes impartially all that drifts over that position. In the case of the north and south drift, the telescope is obliged to be in effect moved so as to point to different parts of the sky and accordingly all of the inequalities of reflection of the different parts of the coelostat mirrors are likely to produce error in the final result.

Chapter VIII.

VARIOUS RESEARCHES RELATING TO THE TEMPERATURE OF THE EARTH AND THE RADIATION AVAILABLE TO WARM IT.

It is extraordinary that changes of the earth's temperature disastrous to life so seldom occur. We are dependent on food crops which, in turn, depend on narrow restrictions of temperature range. For instance, wheat and maize are grown within the belt whose mean yearly temperature lies between 4° and 20° C; oats and barley between $-2°$ and $+20°$ C; rice, 20° to 30°; and potatoes, 2° to 16°. The corresponding temperature ranges measured from absolute zero are but $5\frac{1}{2}$, $6\frac{1}{2}$, $3\frac{1}{2}$, and 5 per cent, respectively. Despite these limiting conditions no migrations of men seem to have been forced by climatic changes within historical times, extending over 5,000 years, and there is no evidence to show that the habitats of food plants have altered their latitudes during this interval. Yet, the temperature of the earth depends upon a balance between the radiations received from the sun and those emitted from the earth, both hindered in their passage through the atmosphere by the loads of dust, water vapor, carbonic acid, ozone, and oxygen which the atmosphere contains, and subject also to the scattering action of the molecules of the atmospheric gases themselves. The moon, which has no atmosphere, has been shown by the experiments of Lord Rosse, Langley, and others to experience changes of surface temperature during a lunar eclipse of a few hours ranging from a temperature well above freezing, even approaching perhaps that of boiling water, to a temperature far below freezing. As the moon is situated similarly to the earth as regards solar distance, we see from this observation the great value of our atmosphere to equalize temperature. On the earth the maximum range caused by night and day, even in deserts, rarely exceeds 20° C. At most stations, the mean daily range is less than 10° C. It seems safe to conclude that human life would be impossible here were it not for the tempering action of clouds, water vapor, carbon dioxide, and ozone in restraining so strongly the escape of radiation from the earth's surface. Although these constituents of the atmosphere make hardly 3 per cent of its weight, they are the all-important agents for this purpose. Oxygen and nitrogen play little part in restraining terrestrial radiation, although they scatter the incoming shorter wave length solar rays powerfully and thus produce the brightness and blue color of the sky.

In preceding chapters we have traced the investigations made of the direct beam of the sun, its losses in traversing the atmosphere, and the variations which it is subject to from day to day and from year to year on account of changes in the solar emission. In the present chapter we shall deal with a number of researches we have made on the brightness of the sky, the radiation of the earth to space, the absorption which the atmospheric constituents, water vapor, carbonic-acid gas, and ozone, offer to the outgoing earth rays, and shall describe several instruments employed in these investigations and tests which have been made on their behavior.

1. THE PYRANOMETER AND THE BRIGHTNESS OF THE SKY.

During the stay of the Smithsonian expedition at Hump Mountain, North Carolina, and also since it has been removed to Calama, Chile, the observers, Messrs. A. F. Moore and L. H. Abbot, made a large number of observations of the brightness of the sky under different circumstances, and the brightness which remains when part of the light is cut off by the branches and leaves of trees, undergrowth, and ferns. This work has been published by them under the title, "The Brightness of the Sky."[1] The following summary is given, which may be compared by the reader with Chapter VI, Volume III of the Annals of the Astrophysical Observatory, where statements of results of investigations of sky brightness at Flint Island, Mount Whitney, Bassour, and Mount Wilson were given. We shall include also the principal results of some measurements of the brightness of the sky at Mount Wilson published under the title "The Direct and Scattered Radiation of the Sun and Stars."[2]

The North Carolina station was located at an elevation of 1,460 meters or 4,800 feet above sea level on the eastern slope of Hump Mountain; latitude 36° 8′ north, longitude 82° 0′ west. Most of the sky radiation observations were made with the instrument resting on a level platform erected on the roof of the observatory. Being located below the summit of the mountain a certain small percentage of the western sky was cut off. This was found to be 5.1 per cent of the total hemisphere. The instrument employed was a two-strip pyranometer such as is above described in Chapter III. The constant of the instrument as measured on many occasions is found to be 2.08 and has remained remarkably constant, for the same value which was found in 1917 at Hump Mountain is now found in South America in 1919 by comparisons of the pyranometer with the pyrheliometer, and besides agrees closely with the value 2.08 computed from the measured dimensions of the instrument.

OBSERVATIONS ON NEARLY CLOUDLESS SKIES.

In the following table, abbreviated from the publication above cited, there are given the results of four cloudless days of 1917 on the general intensity of sky radiation and the effect of the altitude of the sun upon it. The table gives the air

[1] Smithsonian Miscellaneous Collections, vol. 71, no. 4. [2] Astronomical Journal, vol. 33, p. 129, 1914.

mass, M, and the zenith distance, Z, of the sun at the moment of observation, the intensity of the sky radiation on a horizontal surface, H, the intensity of solar radiation by the pyrheliometer on a surface at right angles to the solar beam, Pyrh, the intensity of solar radiation on a horizontal surface, S, the sum of the intensities of solar and sky radiation on a horizontal surface, $S+H$, and the corresponding ratio of solar to sky radiation, S/H.

TABLE 85.—*Sky radiation at Hump Mountain, North Carolina.*

Date.	M.	Z.	H.	Pyrh.	S.	$S+H$.	S/H.	Character of sky, etc.
1917.		° ′						
Aug. 18	4.89	78 27	0.0501	1.037	0.212	0.2621	4.23	Cloudless; hazy along horizon.
	4.17	76 20	.0544	1.100	.264	.3184	4.85	
	3.34	72 45	.0587	1.149	.344	.4027	5.86	
	2.69	68 18	.0638	1.263	.470	.5338	7.37	
	2.03	60 30	.0758	1.342	.661	.7368	8.72	
	1.30	39 30	.0974	1.421	1.093	1.1904	11.23	
26	4.74	78 05	.0467	1.108	.234	.2807	5.00	Very blue; light haze near horizon.
	4.04	75 52	.0500	1.153	.285	.3350	5.71	
	3.40	73 03	.0527	1.213	.357	.4097	6.77	
	2.67	68 09	.0577	1.300	.487	.5447	8.44	
	1.97	59 30	.0657	1.387	.704	.7697	10.72	
	1.25	37 00	....	1.481	1.184	....	....	
Sept. 18	4.75	78 06	.0522	1.017	.214	.2662	4.10	Clear, except slight cirri and haze near horizon.
	4.07	75 58	.0568	1.084	.266	.3228	4.69	
	3.36	72 51	.0620	1.159	.345	.4070	5.56	
	2.71	68 30	.0672	1.242	.458	.5252	6.82	
	2.03	60 30	.0755	1.347	.664	.7395	8.79	
	1.30	39 30	.0895	1.472	1.132	1.2215	12.64	
Oct. 13	4.83	78 18	.0450	1.116	.231	.2760	5.14	Cloudless except small cirri in SE. Little haze; very clear.
	4.13	76 12	.0494	1.200	.291	.3404	5.88	
	3.29	72 27	.0549	1.295	.394	.4489	7.17	
	2.71	68 30	.0589	1.357	.501	.5599	8.51	
	2.03	60 30	.0659	1.447	.713	.7789	10.81	
	1.39	44 00	.0782	1.522	1.095	1.1732	14.00	

The reader will note that the intensity of sky light on the horizontal surface is from one-fourth to one-tenth of the intensity of sunlight on a horizontal surface, depending upon the altitude of the sun. The sky light is brighter relatively to the direct sunlight at times when the sun is near the horizon. In the extended table the range of values of the intensity of sky light on a horizontal surface at the time when the sun's zenith distance was 60° ran from 0.060 to 0.130 calories per square centimeter per minute and the mean was 0.0796. This value may be compared with the mean of 64 days' observations at Calama, Chile, for the same zenith distance of the sun. Although Calama is located nearly 800 meters higher in altitude than the Hump Mountain station, yet being in a region where there is no rainfall the air is more dusty, and accordingly, as might perhaps be expected, the intensity of the sky radiation is nearly as great at Calama as is usual at Hump Mountain on cloudless days. The mean of the 64 days is 0.0757 and the range is from 0.060 to 0.113. On 51 days the total sky brightness on a horizontal surface was determined at Calama for a solar zenith distance of 71°, air mass 3. The mean result was 0.0642 and the range from 0.053 to 0.108.

Many observations were made at Hump Mountain to determine the relative brightness of the different zones of the sky. In the following table a number of these results are given which show the brightness on a horizontal surface from the lower 30°, the middle 30°, and the upper 30° zones of the sky hemisphere. These results are given as percentages of the total radiation of the whole sky observed on a horizontal surface. For an "equal" sky, of which each unit angular area would give the same radiation on a surface at right angles to its beam the corresponding values would be 25, 50, and 25 per cent. Percentage of observed values compared to "equal sky" are given. Both clear and hazy cloudless days are included.

TABLE 86.—*Brightness of zones of the sky as measured on a horizontal surface.*

AT HUMP MOUNTAIN.

Date.	Sun's altitude.	Percentage of total.			Percentage of "equal sky."			Remarks.
		Lower 30°.	Middle 30°.	Upper 30°.	Lower 30°.	Middle 30°.	Upper 30°.	
1917.	°							
Oct. 13	46	32.2	48.7	19.1	128.9	97.4	76.9	Clear and cloudless.
	21	38.4	42.9	18.7	153.6	85.9	74.6	Do.
Nov. 17	30	34.6	43.5	22.0	138.3	87.0	87.8	Clear except very low haze.
Dec. 17	25	38.6	43.9	17.4	154.5	87.9	69.7	Very clear; cloudless.
1918.								
Feb. 23	14	40.6	40.0	19.4	162.3	80.0	77.6	Do.
1917.								
Oct. 17	33	39.3	45.0	15.7	157.6	90.0	62.6	Very hazy; cloudless.
1918.								
Feb. 28	37	39.3	45.8	15.0	157.1	91.5	60.0	Do.

AT CALAMA, CHILE.

1918.								
July 31	37	40.6	39.7	19.7	162.2	79.6	78.5	Clear; cloudless.
Aug. 1	45	36.2	42.3	21.5	144.6	84.7	85.8	Do.
29	35	40.4	41.7	17.9	161.7	83.5	71.4	Very hazy; cloudless.

It is difficult to arrive at any very definite conclusions from observations of this character owing to the many factors involved and the wide variation in these factors themselves. Dust and haziness may alter both the intensity and the distribution of sky light, but the main variable factor is the position of the sun. In order to show the effects of the sun's position on the brightness of the sky, a series of values will be given showing the intensity when the pyranometer is exposed normally to the axis of a cone of light of 60°, the axis of which is inclined to the horizon at the angle of the sun's altitude, and swung around in azimuth from the azimuth of the sun to positions 60°, 90°, 120°, 180° therefrom, respectively. The values so obtained are given in the following table, designated I, II, III, IV, and V, respectively. An additional reading called VI is made with the instrument observing the zenith.

TABLE 87.—*Sky brightness at selected regions.*

Date.	Hour angle, start.	Hour angle, finish.	Sun's approximate altitude, start.	Sun's approximate altitude, finish.	Average calories.						Per cent of I.					Weather and remarks.
					I.	II.	III.	IV.	V.	VI.	II.	III.	IV.	V.	VI.	
1918.			° ′	° ′												
Feb. 11	−1.05	−0.43	37 30	38 30	0.0656	0.0361	....	0.0164	0.0147	0.0178	55.0	......	25.0	22.4	27.1	Fairly clear. Air dry. Brisk NW. wind at intervals.
23	−2.22	−2.05	33 00	35 15	.0334	.0234	0.0189	.0148	.0134	.0133	70.1	56.6	44.3	40.1	39.8	Clear. NW. wind.
23	+3.35	+4.04	21 42	16 54	.0365	.0315	.0192	.0190	.0238	.0120	86.3	52.6	52.0	65.2	32.9	Clear. NW. wind.
26	+2.06	+2.44	36 00	30 52	.0345	.0297	.0190	.0139	.0146	.0129	86.1	55.1	40.3	42.2	37.4	Very clear. NW. wind at intervals.
28	−2.34	−2.15	32 45	35 15	.0649	.0346	.0229	.0175	.0179	.0178	53.3	35.3	27.0	27.6	27.4	Cloudless but haze in valley and to level of observatory. Warmer.
28	+1.22	+1.44	42 00	40 00	.1238	.0782	.0455	.0289	.0230	.0318	63.2	36.7	23.3	18.6	25.7	Very hazy—even above observatory. Warm. Little wind.
Mar. 8	−2.47	−2.29	33 30	36 00	.0402	.0221	.0179	.0153	.0146	.0146	55.0	44.5	38.1	36.3	36.3	Quite clear but haze in valley. Little wind.

The following set was taken without the sun shaded off, i. e., I is the sum of sun plus sky as measured on a horizontal surface. All are taken without sunshade.

			° ′	° ′												
Feb. 23	+0.13	+0.23	44 00	43 30	1.607	0.0304	0.0210	0.0155	0.0127	....	1.9	1.3	1.0	0.8	......	Clear. NW. wind.

The following set was taken in a fairly even and thick cloudy sky. Instrument pointed due south in I. Sun's altitude not recorded but probably about 36°.

Mar. 23	−3.24	−2.49	(?)	(?)	0.0483	0.0536	0.0539	0.0485	0.0353	....	111.0	112.0	100.0	73.0	......	Even and thick cloudy sky.

The following series taken at Calama, Chile, shows the variation of the intensity of the sky radiation around the sun and over the whole sky, observed, respectively, on a surface at right angles to the beam and on a horizontal surface, from early morning until the sun reached a high altitude. The sky observed around the sun was limited to a cone of 30°.

TABLE 88.—*Sky brightness near the sun compared to the whole sky.*

Mean hour angle.	Sun's altitude.	Calories on horizontal.	Mean of x values.	Character of sky.
h. m.	(*a*) Zone around sun.		x	
−5 55	9° 00′	0.0456	3	Cloudless but very hazy. Light east wind.
	(*b*) Whole sky.			
−5 50	9° 30′ (?)	.0535	3	Same as (*a*).
	(*c*) Zone around sun.			
−5 08	18° 54′	.0350	3	Still very hazy—cloudless.
	(*d*) Whole sky.			
−5 03	20° 00′	.0779	......	
	(*e*) Zone around sun.			
−4 18	30° 00′	.0291	4	Still very hazy. Little wind.
	(*f*) Whole sky.			
−4 13	31° 15′	.0936	4	
	(*g*) Zone around sun.			
−2 47	50° 00′	.0250	4	Still quite hazy around sun.
	(*h*) Whole sky.			
−2 41	53° 00′	.1166	4	

OBSERVATIONS ON CLOUDY SKIES.

The results which we have given hitherto were made on cloudless skies. It is interesting and important to know what effect on the quantity of radiation diffused from the skies is produced by the occurrence of clouds. A series of observations upon cloudy skies was taken at Hump Mountain under various conditions. Some of the results are given in the following table.

TABLE 89.—*Radiation from cloudy skies on a horizontal surface.*

Date.	Hour angle.	Mean of x values.	Calories.	Character of sky.
	h. m.	x		
Aug. 6, 1917	−1 32	5	0.596	Clouds fairly thick. Totally cloudy.
	−1 18	5	.502	
	−0 45	10	.564	
Aug. 16, 1917	+4 28	2	.507	Cloudy and partly foggy.
	+4 31	3	.706	
Aug. 31, 1917	−3 26	4	.791	Heavy low fog. These are probably lower because of pyranometer glass coated with fog.
	−3 20	6	.645	
Sept. 1, 1917	−2 56	4	.378	Fairly heavy clouds over whole sky, but sun faintly shining through spots at times.
	−2 44	9	.247	
Sept. 22, 1917	+1 38	6	.202	Very heavy clouds and also low fog. It gradually grew darker, and just after the third set rain began to fall.
	+1 42	3	.129	
	+1 45	4	.072	
Sept. 29, 1917	−1 35	10	.326	Entirely cloudy sky. Clouds very high.
Dec. 3, 1917	−2 28	8	.308	Very cloudy sky. Clouds very even except along horizon. Began raining after last set.
	−2 43	2	.180	
Jan. 19, 1918	+1 32	4	.456	Exceedingly hazy sky. Sun very dim. First and third sets are of the sky alone, and second and fourth of sun and sky—both measured on horizontal surface.
	+1 36	5	.600	
	+1 42	4	.461	
	+1 48	5	.560	
Jan. 31, 1918	+2 09	10	.210	Sky covered with thin cirrus clouds through which sun shone. Sun shaded from strips.

Taking 0.080 calorie as a fair average of the intensity of the radiation on a horizontal surface from a cloudless sky with moderate altitude of the sun it will be seen that for cloudy skies the values are from four to nine times as great with average clouds, and from one to four times as great with extremely heavy clouds. Occasionally when violent rain is about to fall the radiations drop very suddenly to values slightly lower than this. With ordinary low fog such as is dispelled by the morning sun, the indications are that the radiation is tenfold or more that from clear skies excluding the direct sun. An average cloudy sky, with the clouds obscuring the sun, but not especially thick, lets through about as much radiation measured on a horizontal surface as comes from the sun and a clear sky combined when the sun has an altitude of about 15° above the horizon. With low fog, the radiation on the horizontal surface is about the same as with the sun and clear sky, with the sun at about 30° altitude.

It is interesting to know the rate of decline of the sky radiation, as measured on a horizontal surface, as the sun approaches the horizon and passes it at sunset. The following series of observations made at Calama, Chile, December 10, 1918, give information of this character.

TABLE 90.—*March of sky brightness at sunset, Calama, Chile, Dec. 10, 1918.*

Sky cloudless, somewhat hazy, heavy wind at intervals.
Sun disappearing.......... 6^h: 42^m: 00^s H. A.
Sun disappeared.......... 44^m: 18^s.
True sunset (0° altitude).......... 40^m: 20^s.

Hour angle.	Altitude of sun.	Calories.	Hour angle.	Altitude of sun.	Calories.
h m s	° ′		h m s	° ′	
+4 42 45	25 20	0.0878	6 30 45	2 02	0.0195
43	25 06	.0881	31	1 50	.0175
44	24 53	.0871	32	1 37	.0172
45	24 40	.9874	33	1 25	.0172
46	24 26	.0871	34	1 13	.0152
			35	1 01	.0142
5 11 45	18 57	.0741	36	0 49	.0139
12	18 44	.0693	37	0 37	.0129
13	18 31	.0683	38	0 25	.0119
14	18 18	.0693	39	0 13	.0113
15	18 05	.0683	40	+0 01	.0101
5 44 45	11 43	.0553	41	−0 11	.0091
45	11 30	.0536	42	0 23	.0085
46	11 18	.0536	43	0 34	.0078
47	11 05	.0536	44	0 46	.0068
			45	0 58	.0059
6 07 45	6 47	.0382	46	1 09	.0052
08	6 35	.0386	47	1 21	.0038
09	6 23	.0375	48	1 33	.0035
10	6 10	.0372	50	1 57	.0029
11	5 58	.0369	51	2 09	.0023
6 20 45	4 05	.0278	52	2 21	.0021
21	3 53	.0275	53	2 33	.0012
22	3 41	.0262			
23	3 28	.0252	6 54 45	2 45	.0009
24	3 16	.0242	55	2 57	.0006
25	3 04	.0235	56	3 09	.0003
			57	3 21	.0003
6 28 45	2 26	.0202	58	3 33	.0003
29	2 14	.0195	59	3 45	.0003

After the last observation in both places, although the rays had less than 1/200 the intensity of the average total midday sky radiation at Hump Mountain, or at Calama; or less than 1/3000 of the strength of the solar rays reaching the earth, the ordinary small print of a newspaper was easily legible at arm's-length.

RADIATION UNDER THE TREES.

For the use of botanists and agriculturists, we quote also the results obtained at Hump Mountain in measuring radiation underneath the trees of the forest, the undergrowth, and the ferns.

On September 7 the pyranometer, with the auxiliary apparatus, was taken down the mountain side north of the observatory into a grove of beech and black birch. Observations were taken at five spots:

(*a*) In the shade of two large trees, no undergrowth within several feet.

(*b*) Under some rather thick saplings, partly shaded by higher trees, thin undergrowth.

(*c*) In a bed of ferns which covered the instrument, but with an open space directly above.

(*d*) In open space; trees all around; ferns and other vegetation somewhat above instruments toward south.

(*e*) Thick growth of saplings, considerable small vegetation on ground.

The sky on this day was cloudy and very variable. Observations had been taken on the whole sky and sun two hours before the instrument was moved to the grove, but after that the sky became nearly overcast. At the close, observations on the whole sky were taken, but there was so much variation that the readings were of little value.

A few days later, September 12, the observations were repeated with a cloudless sky. With better conditions the readings showed far less variation among themselves than on the preceding days.

On October 2 a third set of observations was taken. The instrument was placed in the same five positions as before. This time the leaves were beginning to fall, and many that remained on the trees had turned yellow. The sky was cloudless and very clear.

Readings were taken mostly in groups of four or five. Below are the times for the middle of each group, the average calories for the group, an estimation of the total sky and sun radiation, and the ratio of the observed radiation under the trees to the estimated radiation above them. The estimated whole sky radiation is based, for September 7, on the observations taken on the tower, following those in the grove; for September 12, on solar observations by the pyrheliometer and total sky observations taken before the pyranometer was moved to the grove; for October 2, on pyrheliometer measurements taken at different air masses during the afternoon, and total sky observations taken in the morning with the pyrheliometer, the sum of the two values at corresponding sun altitudes being used.

Referring to the column of ratios in Table 91, we find a slight increase at *a* between September 12 and October 2. This is to be expected, for in this place the light was obstructed by high leaves, and many of these had fallen. For place *b* we find approximately the same ratio for both days, perhaps because the foliage of the saplings and undergrowth did not fall so early as that of the larger trees. The decrease in the ratio at *c* would follow an increase in the thickness of the ferns. At *e*, under saplings similar to those of *b*, a noticeable increase in the ratio occurred. This was very likely due to the absence of any shadings by higher trees.

TABLE 91.—*Radiation under trees.*

Place.	Hour angle.			Observed calories under trees.			Estimated calories sun and sky.			Ratio of observed to estimated.		
	Sept. 7.	Sept. 12.	Oct. 2.	Sept. 7.	Sept. 12.	Oct. 2.	Sept. 7.[1]	Sept. 12.	Oct. 2.	Sept. 7.	Sept. 12.	Oct. 2.
	h. m.	*h. m.*	*h. m.*									
a.....	−1 18	−0 34	+2 00	0.0136	0.0287	0.0236	0.38	1.28	1.02	0.036	0.022	0.023
b.....	1 10	0 24	2 09	.0145	.0197	.0138	.38	1.28	.94	.038	.015	.015
c.....	1 01	0 16	2 17	.0156	.0140	.0083	.38	1.28	.89	.041	.011	.009
d.....	0 50	0 08	2 26	.0619	.0498	([2])	.38	1.28	.85	.163	.039	......
e.....	[3] 0 34	+0 11	2 38	[3].0144	.0273	.0185	.38	1.28	.80	.038	.021	.023

[1] Sky nearly overcast. Sun appearing only occasionally during morning.
[2] Direct sun on instrument.
[3] There followed seven readings which showed a very rapid decrease of radiation.

The results of these foliage observations are meager, and of small reliability. Nevertheless, they suggest a field for wide and important research concerning the necessary amount of light for various types of plants and at various stages in their development. The pyranometer, supplied perhaps with special colored screens for measuring different kinds of light, seems remarkably well suited to this purpose. It is hoped that a much more extensive investigation along this line may be undertaken.

2. SKY RADIATION AT MOUNT WILSON.

In September, 1913, several series of observations were made on the brightness of the sky by means of the apparatus employed on Mount Whitney in 1910, which is described in volume III of these Annals. Measurements were made on the relative brightness of the sun and sky for different altitudes of the sun and for different altitudes and azimuths of the sky. The observations were subject to the influence of the remnants of the dust which was thrown into the atmosphere by the eruption of Mount Katmai in June, 1912, and hence indicate a brighter sky and less bright direct sun than if they had been taken in a normal year.

Measurements were made on the relative brightness of the sun and sky for different altitudes of the sun, and for different altitudes and azimuths of the sky. The instrument used comprised a bolometer exposing an area about 0.8 by 0.8 millimeter. This was mounted equatorially at the lower end of a tube about 1 meter long and 12 centimeters in diameter, provided with numerous diaphragms having apertures about 10 centimeters in diameter. A quartz lens of 9.5 centimeters clear diameter and 30 centimeters focus, projected the image of a portion of the sun, or of the sky, upon the exposed area of the bolometer. The sky was generally allowed to shine with full intensity through the quartz lens. In order to reduce the brightness of the sun to a similar intensity, one of two diaphragms, with apertures of 3.26 and 5.88 millimeters diameter, respectively, was placed centrally over the end of the tube, a rotating sector whose aperture was 0.0450 that of a complete circle was inserted in the beam, and a resistance of 100 ohms was put in series with the galvanometer, instead of 1 ohm usually employed when observing the sky. As the bolometer measured merely the central part of the sun's image, which by other work we have found to be brighter than the average sun in the ratio $\frac{406}{352}$, this factor was introduced. Altogether the sun observations with the smaller aperture were multiplied by 0.00000304 to make them comparable with those on the sky.

The equatorial instrument was mounted on the tower of the Smithsonian observing station on Mount Wilson, and pointed and operated by Mr. L. B. Aldrich. Dr. Abbot made the galvanometer readings and records and reduced the observations.

On the afternoon of September 22, 1913, three series of pointings were made on the sky. Two consisted of 36 and 35 pointings to all parts of the sky, and the third comprised 18 pointings, taking every odd numbered pointing of the second series. The sun was observed from time to time, and one special set of 10 pointings very near the sun was made. On the forenoon of September 24 practically the same program was repeated, but with the special set of pointings close up to the sun twice carried through. On the whole the observations are very consistent, and as the two days gave nearly the same indications for similar positions in the sky, the results have been combined.

In the reductions the sky positions were reduced to altitude and azimuth, counting the momentary position of the sun as of zero azimuth. Ratios were taken of the observations of brightness, so as to express the brightness of the sky at each position as a fraction of the momentary mean brightness of the sun, for equal angular areas. The results were then collected in groups with respect to altitude. In illustration we give the following values obtained in the first series of September 22:

TABLE 92.—*Brightness of sky in zone of altitude 10° to 20°.*

Altitude.		Azimuth (from sun).		Ratio $\left(\frac{\text{Sky}}{\text{mean sun}}\right)$
°	′	°	′	
14	37	50	00	356×10^{-8}
14	37	34	30	465
17	54	92	40	200
17	54	— 4	45	660
16	20	164	10	204
15	41	—156	10	214
14	30	— 76	40	248

Sky: Mean altitude 15° 56′.
Sun: Mean altitude 46° 0′.

Six such groups of sky observations were arranged, covering the following altitude ranges: 0°–5°; 5°–10°; 10°–20°; 20°–30°; 30°–45°; 45°–65°. There was besides a single observation at altitude 85° 42′.

Each such group of observations was plotted with brightness ratios as ordinates and azimuths (from sun) as abscissæ. Symmetrical curves with respect to the azimuth zero were thus defined. By measuring the area included under each such curve the mean brightness ratio for each altitude zone in question was obtained. Thus were found the following results to represent the six series of sky observations of September 22 and September 24. It should be remarked that for the two short series only five groups were employed.

The figures show some discordances, but it was difficult to draw the curves of azimuth and brightness, in some cases, for lack of observations at critical points. On the whole the comparable results of the two days (by which we mean those of nearly equal solar hour angles) do not differ by above 14 per cent on the average. The ratios are generally somewhat larger for the second day than for the first.

Each of the series, as given in Table 93, was plotted with mean altitudes as abscissæ and mean ratios of brightness as ordinates. Smoothed curves were drawn, and these no doubt aided to improve the results somewhat. From these curves were taken off the values at sky altitudes 5°, 15°, 25°, 35°, 47½°, 65°, and 82½°, corresponding to each series. A difference between the results of the several series depending on the altitude of the sun was very apparent. Accordingly for each of the above 7 altitudes a plot was made with values of the ratio $\left(\text{mean } \frac{\text{sky}}{\text{sun}}\right)$ as abscissæ, and solar altitudes as ordinates. The solar altitudes ranged from 14½ to 46°. The trend of the results was well marked in this interval, and permitted the plots to be extrapolated with much confidence from solar altitude 0° to 90°. This being done, the following values (Table 94) were taken as representing the mean ratio of brightness, $\frac{\text{sky}}{\text{sun}}$ for various sky zones and for certain altitudes of the sun.

TABLE 93.—*Mean brightness of sky zone.*

Sept. 22, 1913.						Sept. 24, 1913.					
Series I.		Series II.		Series III.		Series I.		Series II.		Series III.	
Hour angle of sun.	$1^h 42^m – 2^h 28^m$	$3^h 30^m – 4^h 7^m$		$4^h 24^m – 5^h 1^m$.		$4^h 57^m – 4^h 38^m$.		$3^h 50^m – 3^h 16^m$.		$2^h 12^m – 1^h 40^m$.	
Mean altitude.	Mean $\frac{\text{sky}}{\text{sun}}$.	Mean altitude.	Mean $\frac{\text{sky}}{\text{sun}}$.	Mean altitude.	Mean $\frac{\text{sky}}{\text{sun}}$.	Mean altitude.	Mean $\frac{\text{sky}}{\text{sun}}$.	Mean altitude.	Mean $\frac{\text{sky}}{\text{sun}}$.	Mean altitude.	Mean $\frac{\text{sky}}{\text{sun}}$.
° ′		° ′		° ′		° ′		° ′		° ′	
2 47	550×10^{-8}	2 47	482×10^{-8}	4 36	642×10^{-8}	4 36	766×10^{-8}	2 47	779×10^{-8}	2 47	601×10^{-8}
7 18	366	7 18	515	....	....	....	....	7 18	642	7 18	506
15 56	333	15 56	421	15 50	378	15 50	465	15 56	451	15 56	364
26 5	263	26 5	312	29 46	264	29 46	346	26 5	326	26 5	317
36 46	253	34 36	294	44 59	161	44 59	166	36 36	247	36 36	263
57 15	256	55 12	228	64 16	122	64 16	116	56 29	192	56 29	243
85 42	176	85 42	114	....	....	....	....	85 42	114	85 42	192

TABLE 94.—*Mean ratio of brightness* $\left(\frac{sky}{sun}\right) \times 10^8$.

Sun's altitude.	Sky altitude in zones.						
	0–10°	10°–20°	20°–30°	30°–40°	40°–55°	55°–75°	75°–90°
°							
5	**1200** / 750	490	375	250	130	84	52
15	690	**840** / 460	355	253	160	122	92
25	630	432	**652** / 340	258	200	157	130
35	573	404	320	**511** / 263	230	190	168
47½	500	370	298	265	**399** / 258	236	218
65	390	320	260	275	300	**413** / 300	280
82½	295	270	230	282	340	350	**736** / 358
Area of zone in hemispheres...	0.174	0.168	0.158	0.143	0.176	0.147	0.034

In Table 94 a line of bold-faced figures is seen running diagonally across. The ordinary figures in the same boxes represent the results as thus far explained. Those in bold-face type are introduced to allow for the extraordinary brightness of the sky near the sun. They were obtained in the following manner. As stated above, three sets of observations were made close to the sun. By means of these observations it was found that the immediate neighborhood of the sun was brighter than was allowed for in the general reductions of the sky measurements. This extra brightness was a function of the distance from the sun. Accordingly, the region within 11° of the sun was divided into a number of rings whose areas in terms of a hemisphere were known. Using these data, a weighted mean value of the extra brightness near the sun was determined. In illustration of this we give the following values from the first determination of September 24. The sun's altitude was then 24° 10′.

TABLE 95.—*Brightness of the sky near the sun.*

Solar distance	1°.5	2°	3°	4°	5°	6°	8°	10°
Ratio $\frac{sky}{sun}\times10^8$	23500	16300	8700	5200	3700	2900	2200	1700
Line 2 minus 1000*	22500	15300	7700	4200	2700	1900	1200	700
Ring limits	0°–1°.5	1°.5–2°.5	2°.5–3°.5	3°.5–4°.5	4°.5–5°.5	5°.5–7°	7°–8°	9°–11°
Area of ring$\times10^5$ in hemispheres	33	61	92	121	152	285	486	606
Line 3 times line 5$\times10^8$	†9.9	9.3	7.1	5.1	4.1	5.4	5.8	4.2

* This 1000 is the mean brightness ratio already estimated for this region in the general sky work, so that the figures in line 3 give what is over and above close to the sun.

† Estimated brightness for this ring $30{,}000\times10^{-8}$.

Sum of line $5=184\times10^{-4}$ hemispheres.

Sum of line $6=50.9\times10^{-8}$.

Mean brightness ratio for .0184 hemispheres: $\frac{50.9\times10^{-8}}{184\times10^{-4}}=2770\times10^{-8}$.

This and the other two series of observations near the sun gave the following data:

Average extra brightness within 11° of sun, $\frac{\text{sky}}{\text{sun}}$ 1410×10^{-8}, 2770×10^{-8}, 3140×10^{-8}.

Altitude of sun, 42° 20′, 24° 10′, 19° 0′.

Additional observations at higher sun would have been desirable, but, lacking these, the following values were estimated, after plotting the values given above:

Sun altitude	5°	15°	25°	35°	47½°	65°	82½°
Average value of extra brightness for 11°: $\frac{\text{sky}}{\text{sun}}$ ($\times10^8$)	4,300	3.500	2,650	1,900	1,350	900	700

If a zone of the sky extending from 10° to 20° of altitude be considered to include the sun at an altitude of 15°, a circle 11° in radius about the sun would only partially be included in the zone mentioned. But for simplicity, and in view of the limitations of accuracy of the investigations, we have assumed that it is only the zone 10° to 20° in altitude which is made brighter by the extra brightness near the sun when the sun is at 15° altitude. Thus we have increased the number representing the mean brightness of each zone by finding the weighted mean of its brightness, as given by the general sky observations, and its added brightness as furnished by the special observations near the sun, giving weights in proportion to the areas of the zone and of the circle of 11° radius, respectively. Thus, in illustration, for the zone 10° to 20° we have:

$$\frac{3500\times.0184+460\times.168}{.168}=840$$

This number 840 is found in bold faced type in Table 94 above.

In what has been given above, the quantities of radiation furnished by angular areas of the sky equal to that of the sun are compared with the quantities of radiation furnished in the direct solar beam at particular altitudes of the sun. We now propose to express the intensity of the direct solar beam at different altitudes of the sun in terms of the solar constant of radiation.

All observations of the sun's brightness made during the two days September 22 and September 24, 1913, were collected in connection with the secants of the sun's zenith distance at the moments of observation. A plot was made with values of secant Z as abscissæ, and logarithm solar intensity as ordinates. The tangent of the inclination of the best straight line representing the points was read off. Thus was obtained the apparent transmission coefficient of the atmosphere, for the sun's total radiation, and for the days in question.[3] The value obtained in this way was 0.867. Tables 33 to 36 of Volume III, Annals of the Smithsonian Astrophysical Observatory, were then searched for similar values. On September 18, 1909, the pyrheliometry yielded the value 0.865. On this day the solar constant value, by

[3] See Annals, Astrophysical Observatory, Vol. III, p. 99.

spectrobolometric investigation, was 1.921 calories per square centimeter per minute. The following pyrheliometer readings were made:

Secant Z	2.765	2.267	1.894	1.628	1.421	1.244	1.238
Calories observed	1.160	1.257	1.335	1.375	1.430	1.422	1.438

So far as they go these values undoubtedly represent closely the values which would have been obtained if the pyrheliometer had been read on September 22 and September 24, 1913, at equal altitudes of the sun. Unfortunately these values do not reach to very low sun. In order to get probable pyrheliometer values at very low sun, a comparison was made between the values given above and those obtained on July 6, 1910, when the pyrheliometer was read from sunrise to noon.[4] Combining the results obtained by this comparison with those just given, the following values were chosen as the most probable intensities of solar radiation corresponding to different solar altitudes for September 22 and September 24, 1913.

TABLE 96.—*Brightness of the sun and other data.*

Sun's altitude	5°	15°	25°	35°	47½°	65°	82½°
Sun's intensity in calories per cm² per minute	0.533	0.900	1.233	1.358	1.413	1.496	1.521
Sun's intensity if outside atmosphere it is 1.0	0.277	0.468	0.641	0.706	0.734	0.778	0.791

By combining Tables 94 and 96 the total radiation of the sky and sun for the whole hemisphere may be determined. If one wishes to consider the rays as falling on a horizontal surface, account has to be taken of the cosine of the zenith distance. Take, in illustration, the conditions when the sun is at 47½° altitude:

TABLE 97.—*Brightness of day sky for solar altitude 47½°.*

Zone altitude	0–10°	10°–20°	20°–30°	30°–40°	40°–55°	55°–75°	75°–90°
Area in hemispheres	0.174	0.168	0.158	0.143	0.176	0.147	0.034
Cosine zenith distance	0.087	0.259	0.423	0.574	0.737	0.906	0.991
Ratio $\frac{\text{sky}}{\text{sun}}\times 10^8$	500	370	298	265	399	236	218
Product line 4×line 2	87.0	62.2	47.1	37.9	70.2	34.7	7.4
Product line 5×line 3	7.6	16.1	19.9	21.8	51.7	31.4	7.3

Taking the sum of line five from left to right we find that the mean brightness of the whole sky for equal areas is 346×10^{-8} times that of the sun at 47½° altitude. As the sun at this time occupied 108×10^{-7} hemispheres, and there are approximately 20,630 square degrees in a hemisphere, and as the sun (by Table 96) furnished 1.413 calories per square centimeter per minute, it follows that a square degree of sky furnished on the average $\frac{346\times 10^{-8}}{108\times 10^{-7}}\times\frac{1.413}{20630}=219\times 10^{-7}$ calories per square centimeter per minute.

[4] See Abbot's "The Sun" (Appletons, 1911), p. 287.

Taking the sum of line six from left to right we find that as received on a horizontal surface, the mean brightness of the whole sky for equal areas is 156×10^{-8} times that of the direct sun rays at $47\frac{1}{2}°$ altitude, received at normal incidence. The whole sky therefore would furnish $\frac{1.413\times156\times10^{-8}}{108\times10^{-7}}=0.205$ calorie per square centimeter per minute on a horizontal surface. The sun would furnish to such a surface $1.413\times$cosine $42\frac{1}{2}°=1.041$ calories per square centimeter per minute. The total from sun and sky on a horizontal surface is 1.246 calories per square centimeter per minute. Proceeding in a similar way with the other data of Tables 94 and 96, we reach the following results:

TABLE 98.—*Brightness of sun and sky.*

Altitude of sun	5°	15°	25°	35°	$47\frac{1}{2}°$	65°	$82\frac{1}{2}°$
Sun's brightness, calories per cm^2 per minute	0.533	0.900	1.233	1.358	1.413	1.496	1.521
Sun's brightness on horizontal surface, calories per $cm.^2$ per minute	0.046	0.233	0.524	0.780	1.041	1.355	1.507
Mean brightness $\frac{sky}{sun}\times10^8$, normal	423	403	385	365	346	326	310
Mean brightness of sky on horizontal surfaces $\frac{sky}{sun}\times10^8$, sun normal	115	132	142	150	156	163	170
Mean sky on normal, calories per sq. degree$\times10^7$, per cm^2 per minute	101	163	213	222	219	219	211
Total sky on horizontal, calories per cm^2 per minute	0.056	0.110	0.162	0.189	0.205	0.226	0.240
Total sun and sky on horizontal, calories per cm^2 per minute	0.102	0.343	0.686	0.969	1.246	1.581	1.747

A comparison of Tables 98 and 85 indicates much more sky light at Mount Wilson than at Hump Mountain. But it is to be recalled that higher values were frequently observed at Hump Mountain than those in Table 85, that the very bright sky close to the sun, excluded at Hump Mountain, is included at Mount Wilson, and that the sky of September, 1913, was still hazy by reason of the Mount Katmai eruption of 1912. The Mount Wilson values just given are most valuable for the detailed study of the brightness of all parts of the sky.

3. THE INFLUENCE OF ATMOSPHERIC WATER VAPOR, OZONE, AND CARBON DIOXIDE ON THE TRANSMISSION OF LONG-WAVE RAYS.

Intermittently from 1908 to 1917, Mr. Fowle conducted many experiments on the effects of water vapor contained in very long columns of air at atmospheric pressure to diminish by absorption the atmospheric transmission for the long-wave rays of the solar and terrestrial spectrum. The experiments dealt with all rays between wave lengths 1.2 and 17 μ. They were published in full by the Smithsonian Institution[5], but as they are of fundamental importance to the study of the temperature of the earth, an abstract of them is given here.

It is to be recalled that the radiation from the sun, at an apparent temperature of 6,000° to 7,000° K[6], passes through the atmosphere with comparatively little true absorption. Nearly all of the radiation of a body of this temperature lies at wave lengths shorter than 2 μ. At sea level on a clear day when the sun is in the

[5] Smithsonian Miscellaneous Collections, vol. 68, no. 8, 1917.

[6] In what follows the symbol K denotes absolute temperature in centigrade degrees.

zenith only about 6 to 8 per cent is absorbed from the direct solar beam within the great infra-red bands ρ ϕ ψ ω and χ in its passage to the surface of the earth.[7]

The radiation from a body of the temperature of the earth, which may be taken as about 287° K, is of wave lengths nearly all greater than 2 μ and is hindered by quite a different series of absorption bands in its passage outward through the air. These absorption losses are caused principally by the water vapor, ozone, and carbonic acid gas present in the atmosphere.

In Mr. Fowle's experiments, as illustrated in figure 36, rays emitted from a powerful lamp containing 44 Nernst double glowers, or 88 separate filaments, shone through a large tube 42.5 meters long to a concave mirror of 50 centimeters diameter, which reflected them in a parallel beam through a side tube to a great plane mirror at 16 meters distance, from whence they were reflected back on their course to a focus on the slit of a spectrobolometer close beside the lamp. Thus the rays traversed in the tube a course of 117 meters of moist air. In some experiments

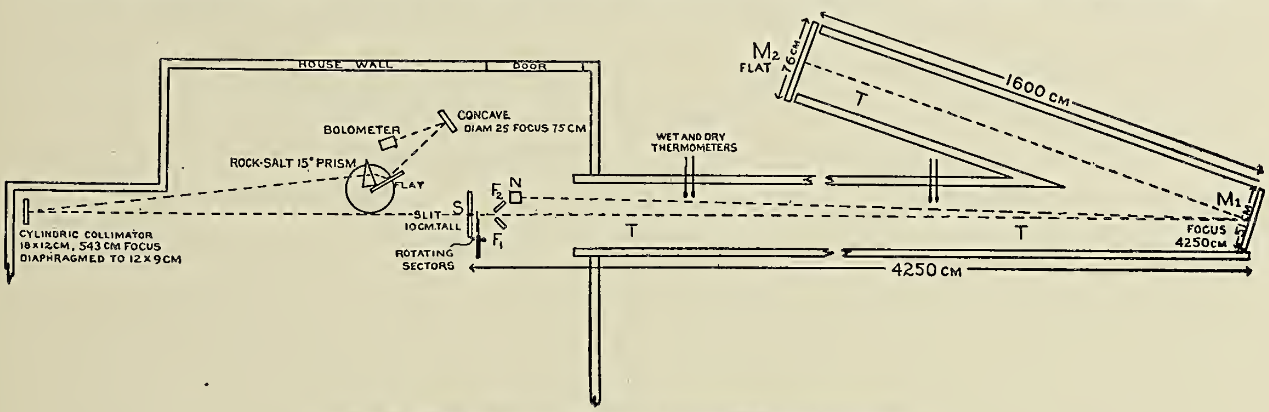

FIG. 36.—Plan of water-vapor tube and spectrobolometric apparatus.

the rays were caused to go over the same course a second time before reaching the slit, making 234 meters in all. By means of a number of wet and dry bulb thermometers scattered along the tube, in which a thorough mixture of the air column was produced by a blower, the prevailing humidity was determined. The humidity values were several times checked by Mr. Aldrich, who absorbed and weighed the water from samples of the air. The spectrobolometer comprised a collimating mirror of 5.43 meters focus; a rock-salt prism either of 60° or of 15° refracting angle, according to the intensity of energy available; a minimum-deviation plane mirror; an image forming mirror of 0.75 meter focus; and a bolometer of 0.1 or 0.5 millimeter width, according to the intensity of energy available. In the spectroscope the beam traversed 11.5 meters of air of measured humidity.

In many of the experiments the lamp shone directly through the spectroscope alone. Thus three lengths of path were available, 11.5, 128.5, and 245.5 meters, respectively. As the experiments covered all seasons of the year, the range of

[7] Astrophysical Journal, 42, p. 406, 1915.

atmospheric water vapor traversed ran from 0.0035 to 0.261 centimeter of precipitable liquid water. That is to say, if the vapor in the length of path of the beam had been entirely precipitated to liquid water it would have produced films of the thicknesses just specified.

In addition to the water vapor the air columns contained carbon-dioxide gas. Corresponding to the three lengths of column available the carbon-dioxide contents were 7, 83, and 160 grams per square meter of cross-section of the air column.

Great difficulties are encountered in such a research which has for its final object the determination of the effect of water vapor to hinder by absorption the escape of terrestrial radiation, and thus to govern in some degree the temperature of the earth.

At first thought it might seem easy to obtain the main object of this research by observing in the laboratory the total radiation of a body at the temperature of the earth, after that radiation had passed through various amounts of atmospheric aqueous vapor. However, the complication then introduced by the radiation from the vapor itself renders the analysis and interpretation of the results difficult if not ambiguous. Recourse is necessary to the use of the radiation from a source at a high enough temperature to make negligible the radiation from the vapor itself and its low-temperature surroundings. But the total radiations of bodies at different temperatures are of different qualities and differently affected by the absorptive powers of the aqueous vapor. In order to apply the results to the case of the earth's radiation, it is therefore necessary to know the absorptions from wave length to wave length and the comparative distribution of energy in the spectrum of the laboratory source of radiation and of the earth. This requires the introduction of the spectroscope with its attending difficulties.

The radiation which it was proposed to observe in the region between 2μ and 20μ is wholly invisible and very feeble even in the emission from the hottest terrestrial sources, so that extremely sensitive measuring apparatus was necessary. Few substances are transparent to it. Glass as a rule is nontransparent for wave lengths greater than 2μ, quartz for those greater than 3μ, and fluorite for those greater than 10μ. A plate of rock salt 1 cm thick absorbs 50 per cent at 17μ and one of sylvite 50 per cent at about 21μ. As sylvite was not available, it was necessary to use rock salt of which the observatory, through the courtesy of the Russian Government, possesses large and beautiful prisms.

Preparations had to be made for observing a great range of intensities. The radiation from a Nernst lamp, such as was used in this research as a source of energy at a temperature of about 2,200° K, is at 20μ only 1/100,000 as intense as it is at 2μ. That there are difficulties inherent in finding proper means for observing accurately over such a range of intensities will be apparent.

No mirror perfectly reflects an incident beam in one direction. An appreciable portion of the beam is scattered in all directions, as may be easily noted by looking from any direction at a silvered mirror upon which a beam of sunlight falls. This scattered light becomes more and more troublesome as that part of the spectrum is approached where the intensity is below 1/10,000 that in the brightest part. Field light, as it is usually called, finally amounts to nearly the whole of the observed energy. Means had to be provided either for eliminating or measuring it.

In order that the air, the transparency of which was to be measured at normal atmospheric conditions as to temperature and pressure, should contain sufficient water vapor, it was necessary to make most of the observations during the hotter summer months. Air of 50 per cent relative humidity at a summer temperature of 40° C contains 12 times as much water vapor as air of the same relative humidity and a winter temperature of 0° C. Even then, with the length of path possible in these laboratory experiments, the air column contained only as much vapor as may be found in the atmosphere during the winter months along the zenith path of the sun's radiation to the earth. On a summer day there may be 10 times as much vapor as this in the sun's path.

In 1908 preliminary experiments were made at intervals between the regular work of the observatory. During 1909 and 1911, in the lack of sufficient sensitiveness of the apparatus for measuring the feeble radiation of the longer wave lengths, certain measures were made connecting the amounts of absorption in the bands of the upper infra-red 0.7μ to 2.0μ, with the quantity of water vapor producing them.[8] These bands are those affecting the incoming radiation from the sun.

When the results of 1913 were reduced during the next winter a serious discrepancy was found, the cause of which was so obscure that it escaped detection for some time. It necessitated the repetition of the experiments in the summer of 1914. This source of error lay in the circumstance that in the form of lamp then used for the radiation source, the bolometer was exposed to a source of somewhat different effective temperature when the radiation passed through the water-vapor tube than when it passed through the spectroscope alone. The comparison of the observed energies in the two cases was to serve as a measure of the absorption due to the water vapor and thus the change in quality of the rays just explained

[8] The results of these observations were published in a series of articles in the Astrophysical Journal discussing the transmission of radiation through moist and dry air and water vapor between the wave lengths 0.35 and 2.0μ. The first (l. c. 35, p. 149, 1912) gave the laboratory calibration, with known amounts of water vapor, of the intensity of energy in the bottom of certain absorption bands, the depths of which could be accurately measured bolometrically. The second (37, p. 359, 1913) gave applications of the first paper to the spectroscopic determination of the water vapor above Mount Wilson and a comparison of these values with determinations by Hann's formula. The third (38, p. 392, 1913) treated of the nonselective scattering of dry air and water vapor for the spectrum region 0.35 and 2.0μ. The fourth (40, p. 435, 1914) was concerned with the application of the dry-air transmission coefficients to the determination of Avogadro's constant, the number of molecules in a gram-molecule of any gas. The fifth (42, p. 394, 1915) gave the corresponding selective absorptions in the spectrum region 0.35 to 2.00μ. Several of these papers are to be found also in the appendix to Volume III of these Annals.

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caused error. This error was avoided by the use of proper diaphragms and the construction of a more suitable and far more effective form of lamp. Some doubt as to the matter of field light required further observations during the summer of 1916. Because of complications resulting from the absorption of the radiation by carbonic-acid gas, further observations were made during some very cold days of the winter of 1916–17. On such days the losses due to aqueous vapor would be at a minimum, whereas the carbonic-acid gas would be practically as effective an absorber as in the summer time. Finally, because of both the unexpectedly small absorption of radiation at the longer observed wave lengths and the too small quantity of aqueous vapor possible in the laboratory experiments, observations were made in April, 1917, of the atmospheric absorption of the radiation from the sun itself.

The necessity of the simultaneous right working of many unruly things, the galvanometer, the bolometer, the source of radiation, a transformer working far beyond its capacity to furnish current for the lamp, the need of sunny weather for making the bolographic record, not too damp for the use of rock salt nor too windy for the galvanometer or bolometer, and without too many of the ever-prevalent summer cumuli—all these requirements tended to make the securing of good observations a tedious process. Often, too, all the difficulties had to be overcome single handed.

A great many details, of high interest indeed for all workers in this domain of experimentation, but indispensable to convince readers of the accuracy of Mr. Fowle's results, are to be consulted in the original publication. They include a study of stray light and means of avoiding or estimating it; a mathematical treatise on the correction of energy curves to allow for widths of slit and bolometer; means for reducing energy intensities in definite ratios; means of allowing for the absorption of apparatus; corrections for diffraction; corrections for emission of shutter; and many other hardly less important subjects.

OBSERVATIONS ON WATER VAPOR AND CARBON DIOXIDE.

The observations fall into two classes. (1) Measurements with the 60° prism and 0.1 millimeter bolometer covering the spectrum region 1.2μ to 9.0μ. (2) Measurements with the 15° prism and 0.5 millimeter bolometer covering the spectrum region 1.2μ to 18μ. In both spectrum regions, but especially in the second, great changes of intensity occur. Correspondingly, regulations of intensity by rotating sectors and by changes of slit width were made. Allowances were made for these changes as accurately as possible. They affected the ordinates of the curve not merely directly, but also by changing the purity of the spectrum. Both the slit and the bolometer widths were taken into consideration in the corrections.

Figure 37 gives an original bolograph and two corrected energy curves of the Nernst lamp radiation observed through the spectroscope alone. Curves *a′* and *b* correspond to 0.01 cm and 0.1 cm of precipitable water, respectively. As a comparison the computed curve for a perfect radiator at 2,200° K is also given. This allows us to note how powerful is the absorption of H_2O and CO_2 in the bands even when so short a path as 11.5 meters is traversed by the beam. In other parts of the spectrum, free from great absorption bands, it will be seen that the computed curve is a very perfect match for the observed ones. This indicates that the Nernst glower spectrum distribution is approximately that of a "perfect radiator" from 1.2μ to 9μ, and this fact was a valuable one in the work.

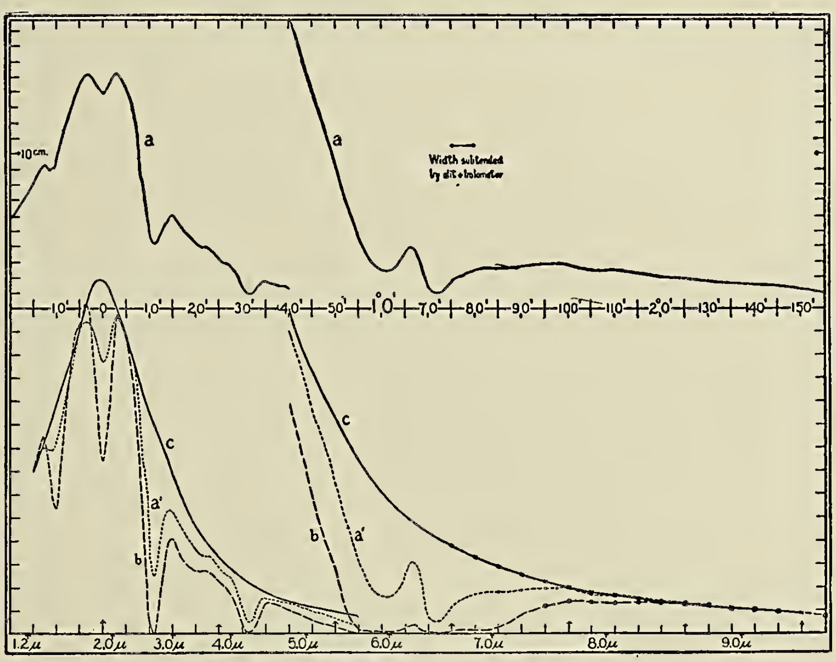

FIG. 37.—Energy curves of Nernst lamp radiation.

Figure 38 shows the percentage of absorption found at all wave lengths from 1.2μ to 9.0μ, with different quantities of water vapor and carbon dioxide in the path. A curve (the fine dots) from the work of Paschen is included. Other data of his are quoted in the original paper leading to separate determinations of the proportions of the absorption due to water vapor and carbon dioxide, respectively.

In the following table the results on the absorption of water vapor to 8μ are numerically expressed. Two columns are added to the table to show the distribution of energy in the spectrum for perfect radiators at 2,200° K and at 287° K, respectively. The former is the temperature of the Nernst lamp, the latter the mean temperature of the air near the earth. The energy numbers for the two sources are not immediately comparable, being on different arbitrary scales. They are given to indicate the changed relative importance of the absorption bands of water vapor in the spectra of different sources.

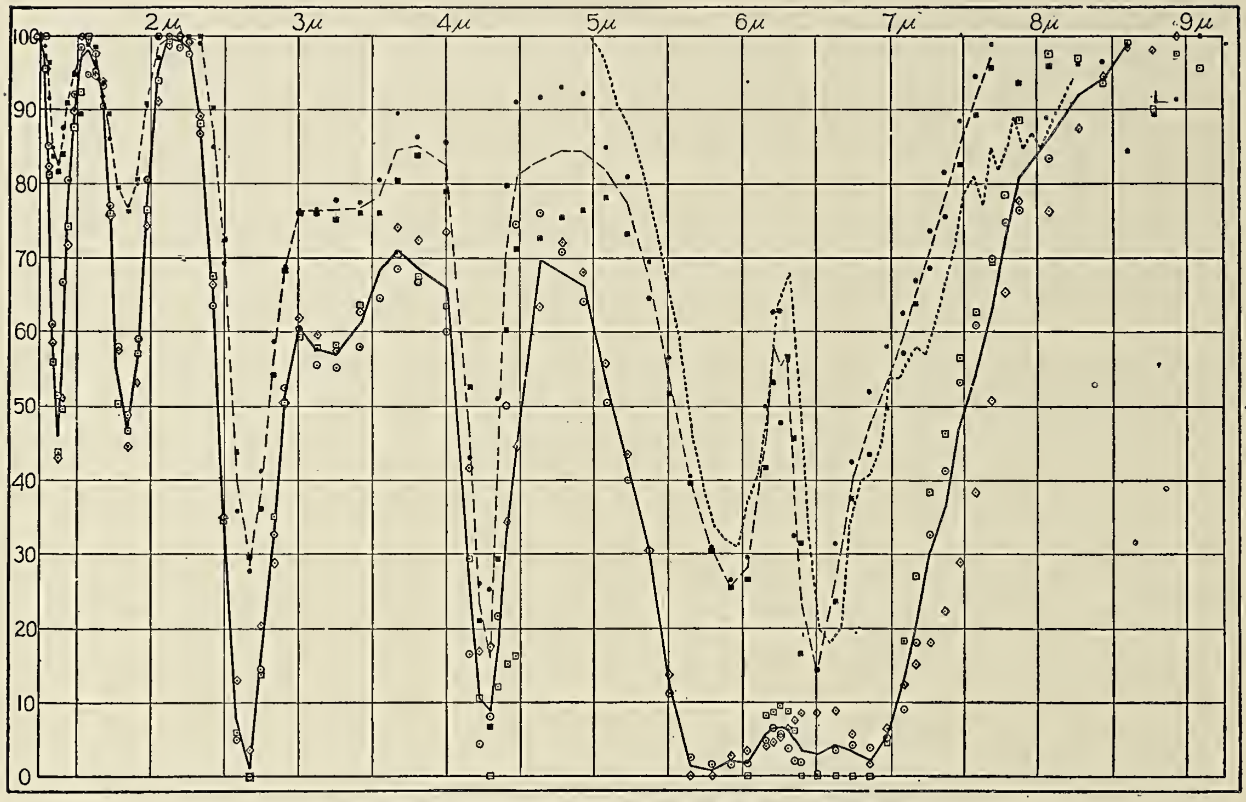

FIG. 38.—Percentage absorptions obtained with 60° rock-salt spectrum.

Lower curve, 0.082 cm ppt. H_2O, 83 grams CO_2 in m^2 path. } Atmospheric conditions.
Middle curve, 0.008 cm ppt. H_2O, 7 grams CO_2 in m^2 path. }
Upper curve, 0.004 cm ppt. H_2O, 0 grams CO_2 in m^2 path. {Steam, 100°C. 76 cm. total pressure.
Abscissae are wave lengths; ordinates, percentage transmissions.

TABLE 99.—*Absorption by water vapor, 1.3 to 8μ.*

Band.	Range of wave length μ.	Relative energy 2,200° K, black radiator.	Percentage absorbed. Precipitable water in cm. 0.008	0.082	Relative energy 287° K, black radiator.
Ψ	1.3 –1.75	2, 300	6.1	18	0
Ω	1.75–2.2	2, 150	13.6	29	0
X	2.2 –3.2	2, 400	23.6	41	1
—	3.2 –4.0	1, 050	21.7	37	38
Y	4.0 –4.9	640	32.5	50	418
Z	4.9 –5.4	210	18	42	440
Z	5.4 –5.9	150	47	85	545
Z	5.9 –6.4	120	64	97	915
Z	6.4 –7.0	110	68	97	1, 340
Z	7.0 –8.0	120	25	62	2, 570
Z	4.9 –8.0	710	[1] 40	[1] 73	5, 810
All	1.3 –8.0	9, 250	[1] 19	[1] 34	6, 267

[1] These figures give the percentage of radiation from the Nernst lamp (2,200°–300° K) absorbed in the band Z (4.9 to 8 μ) and in the whole region 1.3 to 8 μ. The corresponding figures obtained by means of columns 4, 5, and 6 for a distribution of energy of a black body radiating at the temperature of the earth (287° K) to space (0° K) would be 43 and 42 per cent for 0.008 cm ppt. H_2O and 76 and 74 per cent for 0.082 cm ppt. H_2O.

We now pass to the work, done with the 15° prism and 0.5 mm bolometer, which extended to greater wave lengths. At first the region from 1.2μ to 9μ was repeated with this arrangement of apparatus so as to determine, by comparison with what had been done before, some of the corrections necessary under the new conditions.

In the accompanying figure 39 are given a large number of corrected energy curves which were taken with differing quantities of water in the path, and may be compared with the smooth curve of the perfect radiator to indicate the absorption produced. Running across the figure will be noted a heavy black smooth curve just above which are indicated the wave lengths. This is a black-body spectrum curve of a source at 2,200° K, radiating to one at 300° K, as computed from Planck's formula with C_1 equal to 9.23, and C_2 equal to 1.445 for λ in cm for a 15° rock-salt

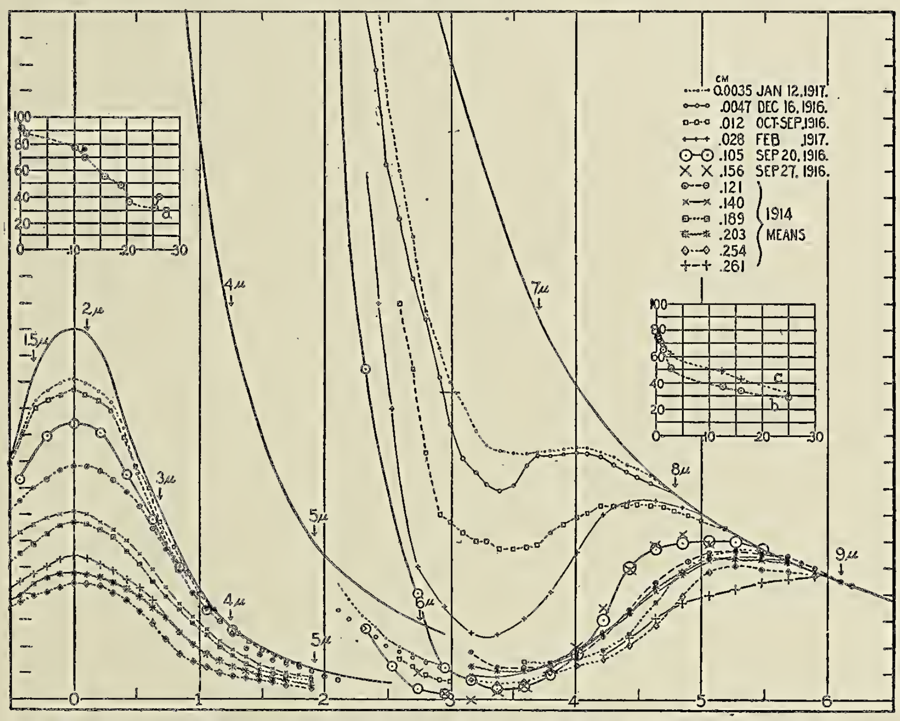

FIG. 39.—Energy curves showing absorptions produced by water vapor, 15° rock-salt spectrum, 2 to 9 μ.

spectrum. The curve is in three sections, the ordinates of the second and third section being multiplied relative to the first by 5 and 50, respectively.[9] The plate

[9] The energy curve is formed for a body radiating from 2,200° K to one at 300° K, because the deflection observed with the lamp may be considered as due to the radiation from a body at 2,200° K radiating to the bolometer, while the deflection due to the insertion of the screen at 300° K may be considered as the radiation from a body at 300° K to the bolometer. Hence the observed intensity of the lamp is really the difference of the deflections in the two cases and should therefore be compared with the black-body curve as drawn. The ratios of the radiation from a body at 300° K to that from one at 2,200° K, both radiating to absolute zero, are shown in the following table:

Ratio of radiation from a body at 300° K to that of a body at 2,200° K.

Wave length	2μ	6μ	8μ	10μ	12μ	14μ	16μ	18μ	20μ
Ratio	1×10^{-8}	0.00067	0.0031	0.0075	0.013	0.020	0.026	0.033	0.038

To a wave length of about 7μ the radiation of the shutter is negligible. At 6μ the observed radiation of the lamp needs to be increased one-tenth of 1 per cent, and at 20μ by 4 per cent in order to represent what it would be if radiating to absolute zero.

distances, proportional to prismatic deviations, taking as zero the deviation at 1.838μ, are indicated by the numbers at the bottom of the plot.

Underneath these three branches of the black-body curve computed for a temperature corresponding to the "black-body" temperature (2,200° K) of the Nernst lamp will be found curves representing the energy spectrum of the lamp through increasing amounts of aqueous vapor. These amounts, as indicated in the table on the plot, range from 0.0035 to 0.012 cm ppt. H_2O when observed through the spectroscope alone; and from 0.028 to 0.261 when observed through the tube. Each curve is the mean of several sets of observations.

For the curves with 0.0035 to 0.012 cm ppt. H_2O there were 7 grams carbon dioxide, and in all the others, except the one with 0.254 cm ppt. H_2O, there were 83 grams carbon dioxide in a 1 m square path; for that one there were 160 grams.

In the small figure in the upper left-hand corner will be seen a curve (marked *a*) which shows the percentage change in area of the maximum between 1.25 and 3μ plotted against the ppt. H_2O in cm as abscissæ. In the other small figure the similar function is plotted for the region between 5 and 9μ. Curve *b* was read from the large plot and is for a distribution of energy for a body like the Nernst lamp at 2,200° K. Curve *c* was computed for a distribution of energy for a body at a temperature of about 287° K, which is about the mean temperature of the air near the earth. Table 100 gives more in detail the data from which curves *b* and *c* were drawn. It will be noted in the main curves of figure 39 that between 6 and 7μ the absorption is practically complete for ppt. H_2O of 1 mm or more.

TABLE 100.— *Water-vapor absorption 5 to 9μ.*

Range of wave lengths.	Relative energy black-body spectrum.		Percentage absorption. Precipitable water in cm.						
	2,200° K, Nernst lamp.	287° K, earth.	0.0035	0.0047	0.012	0.028	0.125	0.16	0.25
5–6μ	1,690	142	18	22	25	43	55	59	65
6–7μ	947	242	48	54	69	85	95	95	95
7–8μ	537	315	15	19	34	42	66	76	83
8–9μ	388	360	0	0	2	2	8	13	35
5–9μ	3,562	1,059	....	....	....	....	....	....	....
5–9μ	Lamp.	....	24	27	35	49	63	66	71
5–9μ	....	Earth.	18	21	30	38	51	57	67

Figure 40 is a continuation for wave lengths longer than 9μ of the curves shown in figure 39. The scale of abscissæ is much more condensed. The ordinates of the two right-hand branches are magnified ten-fold relative to the first or left-hand branch. The extreme right-hand curves represent only the work of 1916–17. As there are so many observations it was thought best to shift the abscissæ of the 1916–17 work five deviation units to the right to avoid confusion.

As in figure 39 so in figure 40, above the first two branches is given the computed black-body curve corresponding to the effective temperature of the lamp. Just below it is another heavy line. It represents the mean of observations of the last three years mainly through the spectroscope alone and within a range of water vapor from 0.003 to 0.028 cm ppt. H_2O. Within this small range of ppt. H_2O no systematic differences were found. While the "black-body" curve agrees closely with the energy curve of the Nernst lamp as far as 9μ, the lamp seems to fall more and more short of being a perfect radiator for longer wave rays.

Observations on a cold day were desired for three purposes: First, to permit the comparison of the curve just described with one through the tube with an amount of vapor of the same order. Generally the tube contained more than tenfold this

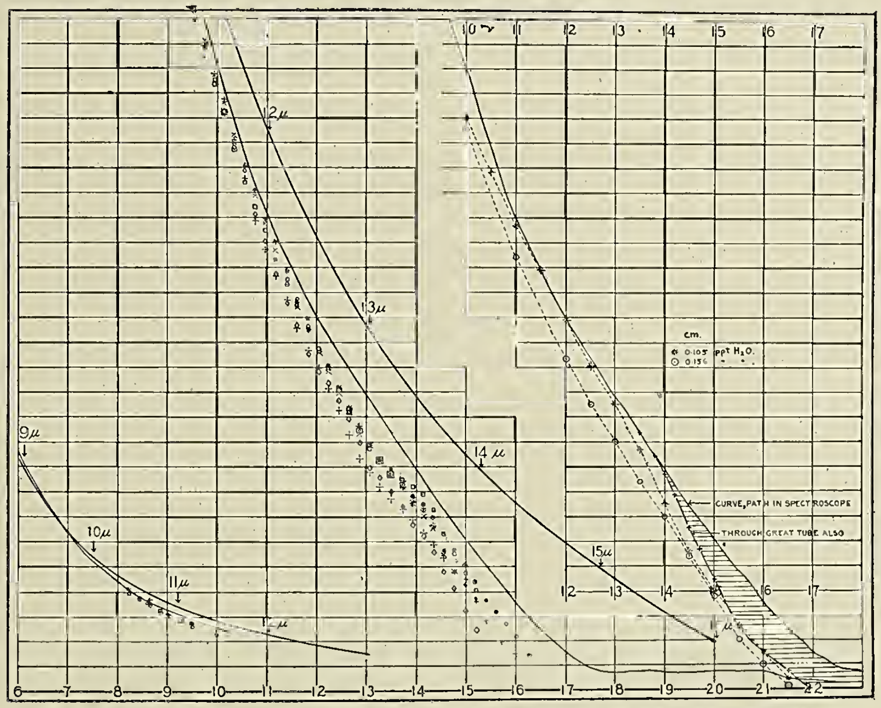

Fig. 40.—Energy curves showing absorptions produced by water vapor, 15° rock-salt spectrum, 9 to 17μ.

amount of water vapor. Second, from a comparison with the mean curve just described to form some estimation of the effect of carbon dioxide. It was supposed that on a very cold day the absorption due to the water vapor in the tube would be so nearly the same as with the observations through the spectroscope alone that the differences would be negligible and thus the increased effect of the carbon dioxide in the tube would be unmasked. Its effect, since its amount in the tube is probably quite constant from day to day, could be eliminated then from the aqueous-vapor effects. Third, if coincidence of the two curves taken with different slit widths occurred, it would serve to assure the absence of errors from diffraction in the tube observations.

Such a cold day was finally obtained in February, 1917, with only 0.028 cm ppt. H_2O in the optical path. An excellent set of observations was obtained and the mean result of the day, so far as it diverged from the curve of the spectroscope alone, is plotted with simple crosses under the extreme right curve (1916–17 observations). It shows: First, that an increase in water vapor from 0.003 to 0.03 cm (tenfold) produces no appreciable change in transparency of the region from 9 to 13.4μ. Second, that beyond 13.4μ the additional carbon dioxide contained in the tube becomes very effective, and produces practically complete absorption at about 14.6μ. The cross-hatched portion shows the proportion of energy cut off by absorption. This may be assumed to be the added effect due to the carbon dioxide in the tube over that present in the spectroscope.

In Table 101 will be found the percentages of absorption at various wave lengths greater than 9μ as indicated from all the experiments. The values are grouped with regard to the quantity of ppt. H_2O traversed by the beam, but the results of the years 1914 and 1916–17 are kept separate.

TABLE 101.—*Water-vapor absorption, 9 to 14μ.*

Cm ppt. H_2O.	9 μ.	10 μ.	11 μ.	11.5 μ.	12 μ.	12.5 μ.	13 μ.	13.5 μ.
Up to 0.03.......	0	0	0	0	0	0	0	0
0.10..............	0	0	0	......	2	0	3	15
0.15 (1914).......	0	0	......	2	3	8	14	15
0.16 (1916–17)...	0	0	......	......	8	11	15	21
0.25 (1914).......	0	......	......	3	8	13	24	26

NOTE.—0 indicates no effect detected.

EXPERIMENTS ON THE SOLAR SPECTRUM.

Supplementing the observations of water-vapor absorption of Nernst lamp rays in the great tube, experiments with the same apparatus were made on the solar spectrum in these long wave regions at different altitudes of the sun. Nearly simultaneously bolographs were taken with the solar spectrobolometer now in Chile, but then just finished in Washington, to determine by Fowle's spectroscopic method the quantities of precipitable water vapor traversed by the solar beam. Great precautions and pains had to be taken to avoid error from field light in the long-wave solar-spectrum work. These are fully described in the original publication.

The observations on the long-wave-length spectrum of the sun will be found reproduced in figure 41 after due allowance for slit plus bolometer widths and field light.

Again the evidence indicates a great transparency for the aqueous vapor in the atmosphere from the wave length 9μ to perhaps 12 or 13μ. No systematic decrease in the heights in this region of the energy curves with increasing aqueous vapor is found.

The band central at 10μ, probably due to ozone (Ladenburg and Lehman, Annalen der Physik 21, p. 305, 1906), is the only place within this wave-length region which shows a consistent decrease of energy with increasing air mass.

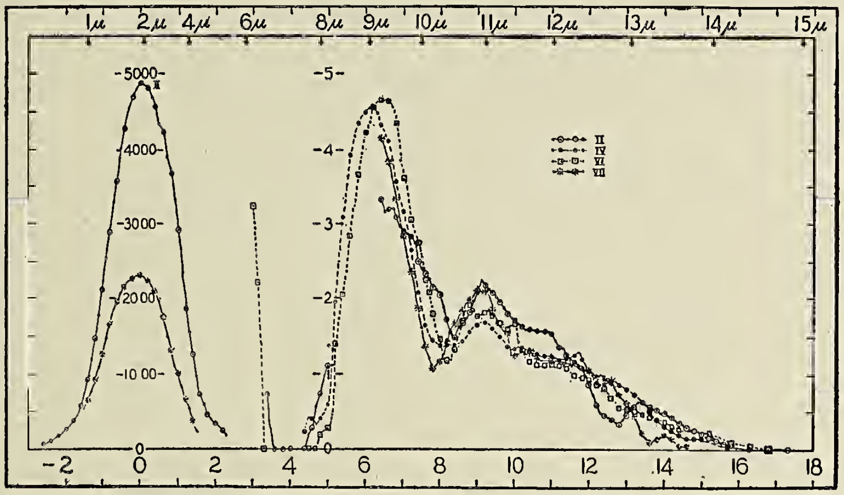

FIG. 41.—Energy curves of 15° rock-salt spectrum of the sun, 1 to 15 μ.

Curve II; air mass, 1.5; ppt. H_2O, 0.7 cm.
Curve IV; air mass, 2.1; ppt. H_2O, 1.1 cm.
Curve VI; air mass, 3.0; ppt. H_2O, 2.0 cm.
Curve VII; air mass, 4.1; ppt. H_2O, 3.0 cm.

This ozone band deserves much further consideration and experiment. As Fowle's work and later work of Aldrich show, water vapor and carbon dioxide cut off almost wholly all of the terrestrial emission to space, except between 8.5μ and 14μ. Between these limits neither of these atmospheric constituents nor any others except ozone appear to produce much diminution of the atmospheric transparency. Compare the tremendous effect of low sun on the intensity of the solar spectrum from 1μ to 4μ as revealed in the figure just given, with its hardly observable effect (except in the ozone band) from 8.5μ to 14μ.

Ozone does not exist at low levels of the atmosphere. None of Fowle's tube work shows any indication of the great band near 10μ. It is a gas formed high in the rare upper atmosphere, and probably continually changing in its amount with changes of the solar radiation, the electrical state of the atmosphere, etc. The powerful absorption band near 10μ must therefore be not only an influential but a variable factor in determining the terrestrial temperature.

COLLECTED RESULTS ON ATMOSPHERIC ABSORPTION FOR LONG-WAVE RADIATION.

Table 102 contains a summary of the results on the absorptive power of atmospheric water vapor and their application to determine the total radiation outwards vertically to space from the earth when the atmosphere contains 0.003, 0.03, 0.3, and 3.0 cm precipitable water. The effect of carbon dioxide and the band of unknown origin at about 10μ has been included.

TABLE 102.—*Atmospheric absorption of earth radiation.*

Range of wave length.	Energy of black body 287° K.	Percentage absorption.			
		Precipitable water in cm.			
		0.003	0.03	0.3	3
μ					
3– 4	5	10	30	50	75
4– 5	50	15	45	70	95
5– 6	142	16	43	66	95
6– 7	242	45	85	95	100
7– 8	315	13	42	85	100
8– 9	360	0	2	40	50
9–10	380	0	0	0	15
10–11	370	0	2	5	40
11–12	350	0	0	4	10
12–13	320	0	0	13	20
13–16	810	100	100	100	100
16–20	510	(90)	100	100	100
20–30	900	(70?)	(80?)	(90?)	100
30–40	300	(100?)	(100?)	(100?)	100
40–50	150	(100)	(100)	(100)	(100)
50–60	75	(100)	(100)	(100)	(100)
3–60	5.279	49	57	66	75

[1] See Smithsonian Physical Tables, seventh revised edition, p. 308, 1920, for a somewhat more elaborate table for computing the transmission percentage of radiation through moist air containing CO_2.

PROPORTION OF TERRESTRIAL RADIATION TRANSMITTED TO SPACE.

In accordance with the values given in the last line of the table the vertical transmissions of the earth's radiation are therefore 51, 43, 34, and 25 per cent, corresponding to 0.003, 0.03, 0.3, and 3 cm ppt. H_2O. Further, applying these last figures to the transmission of radiation outwards in all directions from a horizontal surface at sea level, assuming Lambert's cosine law, and 1 cm ppt. H_2O, it is found that 28 per cent of the earth's radiation under such circumstances passes directly out to space.

Considering the rate of growth of percentage absorption with increasing atmospheric humidity as shown in the last line of the table, and considering[10] (1) that owing to the abundance of atmospheric humidity over the oceans and the Tropics the average precipitable water is to be regarded as 3 cm; (2) that the outgoing terrestrial radiation is emitted at such angles of emergence that the air mass of average emergence is 1.8 times that of zenith transmission, (3) that the absorption of ozone in the high atmosphere seems to cut off one-fifth of the surface terrestrial radiation transmitted by the lower atmospheric layers, we conclude that of the earth's total surface emission it is unlikely that more than 20 per cent is transmitted by the atmosphere to space in fair weather. Allowing for total absorption 50 per

[10] See Annals, Vol. II, p. 132.

cent of the time by clouds, the final result is 10 per cent as the transmission to space from the earth's surface.

4. VARIOUS OBSERVATIONS ON THE PROPERTIES OF COMMON SUBSTANCES WITH RESPECT TO LONG-WAVE RAYS.

In the years 1917, 1918, and 1919, Mr. Aldrich made a great many observations on long-wave rays at Mount Wilson and Washington. In some cases the source of radiation was a lampblack painted metal surface at temperatures from 20° to 100° C. In some cases sources at higher temperatures were employed. Absorbing plates of fluorite, sylvite, and rock salt were often inserted to indicate the quality of the rays as regards wave length. The measuring instruments most employed were the pyranometer, a Coblentz thermopile (kindly loaned, together with some fluorite reflecting plates, by Dr. Coblentz, of the United States Bureau of Standards) and in later experiments a thermopile of 18 tellurium-platinum elements prepared by Aldrich.

A. Does the earth's surface lose any considerable heat by exchanges of radiation to the atmosphere and to space?

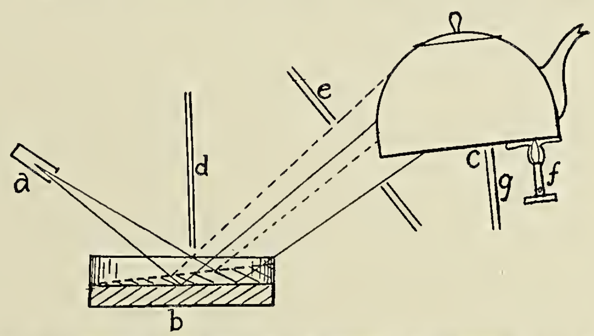

Fig. 42.—Diagram of long-wave ray experiments. a=thermopile. d, e, g= screens. b=mirror. f=lamp. c=tea kettle.

A pyranometer was provided with a metallic hemispherical cover polished outside, blackened within, instead of its glass hemisphere which was removed. The top of the metal cover was cut away to leave a circular aperture whose solid angle as viewed from the strip of the pyranometer was 0.038 hemisphere. In a recess of the cover above this limiting diaphragm could be inserted polished plates of fluorite, rock salt, or sylvite, each 3.4 to 4 mm thick.

As thus arranged the pyranometer was exposed at Mount Wilson on autumn nights of the year 1917 to determine the outgoing radiation with and without the absorbing plates. In some exposures the instrument was inclined at the mean altitude of 40° above the horizon, but usually it looked vertically. The atmospheric humidity and prevailing temperature were determined by the wet and dry thermometers. In all experiments with the plates it is to be recalled that 7.5 to 8 per cent of the rays would be reflected at the two surfaces, so that where about this amount is cut off on introducing a plate the effect is not to be attributed to absorption. Each determination to be given below is the mean of many measurements, in which the ammeter readings on the compensating current ranged at about 0.080. The individual measurements could hardly be made better than to about 3 per cent, taking into account the square of the current strength. Hence the individual determinations of the percentages cut off by the absorbing plates, being differences of nearly equal quantities each apt to be in error by 3 per cent or more, are rough. They indeed range widely. But the mean values, to be given below, seem to yield rather definite conclusions. We give all determinations, but the reader should note that those of September 29 and October 3 are perhaps entitled to most weight.

TABLE 103.—*Summary of pyranometer work on Mount Wilson tower with absorbing plates.*

Date.	Air temperature.	Pressure aqueous vapor.	Percentage radiation cut off by plate.			Remarks.
			Rock salt.	Sylvite.	Fluorite.	
1917.	*C.*°	*mm.*				
Sept. 12	16.7	3.4	16.5	21.6	....	
14	21.5	3.3	12.2	10.7	....	
17	23.2	3.0	13.0	11.0	58	
	23.4	2.4	12.8	7.9	60	
20	17.8	3.0	9.6	12.0	57	
22	11.6	2.9	9.8	0.0	69	
	11.2	3.4	[1] 33.0	[1] 24.0	69	
26	8.5	4.1	20.5	5.0	66	
	8.0	3.7	5.7	13.8	68	
	8.0	3.7	16.7	12.0	64	
	....	....	12.6	6.2	65	
29	10.6	7.3	3.0	0.0	69	New disks of rock salt and sylvite. Fluorite plate repolished
	9.2	6.4	7.2	5.0	67	
Oct. 3	10.6	4.9	6.5	12.8	62	
	11.0	5.1	5.3	8.2	64	
	....	....	9.8	10.6	....	
Mean, all.	....	4.0	10.7±3.1	9.1±4.0	64.4+2.6	All above observations with vertical exposure.
Mean, new disks.	....	5.9	6.4±1.2	7.3±2.5	65.5±1.7	
Sept. 17	23.2	3.0	3.5	1.5	63.5	These four observations at 40° altitude.
	23.4	2.4	0.0	0.0	55	
22	11.6	2.9	7.8	15.0	75	
26	8.0	3.7	11.8	8.6	68	
Mean.....	....	3.0	5.8±2.6	6.3±3.4	65.4±4.8	

[1] Omitted in the means.

From these results it seems improbable that much radiation exceeding the wave length transmissible by the rock-salt plate is transmitted by the atmosphere to levels appreciably cooler than the instrument. The percentage cut off on introducing the plates of rock salt and sylvite is probably attributable altogether to reflection. Plates of rock salt, sylvite, and fluorite of 4 mm thickness absorb as follows, according to data collected in Kayser's "Spectroscopie:"

ROCK SALT.

Wave length, μ	15	17	18	19
Absorption, %	6	23	40	61

SYLVITE.

Wave length, μ	18	20	23.7
Absorption, %	6	19	52.5

FLUORITE.

Wave length, μ	8.2	8.8	9.4	10.0	11.0
Absorption, %	9	19	32	51	83

From these figures we conclude that no considerable heat is lost from the earth's surface by radiation exchanges with the cooler atmosphere, or with space, beyond a wave length of 20μ, which is the practical limit of the transmission of the rock-salt plate. About 60 per cent of the radiation emitted toward space is shown by the observations to lie between this wave length and the practical limit of transmission of the fluorite plate which lies between 9μ and 11μ. From these results and Fowle's researches we may probably conclude that about 60 per cent of the outgoing radiation lies between 10μ and 15μ, and the remaining 40 per cent between 8μ and 10μ. Outside these limits, 8μ to 15μ, the earth's surface loses little heat by exchanges of radiation upward.

B. Does the sun's beam, as it reaches the earth's surface, contain any considerable amount of radiation beyond a wave length of 15μ?

This question was not fully solved.

Assuming that the sun's radiation is similar in spectrum distribution to the rays emitted by a perfect radiator at 6,000° absolute centigrade, but allowing for the known weakness of solar rays in the violet, it may be shown that about 3/10,000 of the solar energy might probably be found at the earth's surface in wave lengths exceeding 15μ, if these long-wave rays are not cut off at all in passing through the atmosphere. It is to be supposed, however, from Fowle's researches and the results just given under heading "A," that such rays would be nearly completely absorbed within the atmosphere. Experiments made by Aldrich in 1917 on Mount Wilson seemed to confirm this probability. But they are not sensitive enough to be fully conclusive on so minute a proportion of the sun's rays and will be repeated before publication.

C. How nearly is water a perfect radiator for long-wave rays?

Water forms upward of 70 per cent of the surface of the earth. Besides this it is a very large constituent of vegetation, and moisture is plentiful in the soil. Clouds, which cover on the average 50 per cent of the earth, are also of liquid water.

The question is therefore of special importance for a knowledge of the earth's emission.

The following experiments made by Aldrich at Mount Wilson and at Washington in 1917 seem to give definite indications. Observations were made with the arrangement of apparatus shown in figure 42. On October 2 at Mount Wilson the dry mirror reflected upon the thermopile rays to give 1.60 cm deflection of the galvanometer. These rays were emitted from the outside of a water pail at 75° C, blackened with lampblack paint. With distilled water upon the mirror so as to give a path in water of about 2 cm the rays reflected to the galvanometer by the mirror give a deflection of 0.00 cm. To prove that the mirror was still properly adjusted, a lamp was substituted for the hot pail. A deflection of 3.3 cm resulted. In another experiment, October 4, with 30 cm deflection from the dry mirror, a deflection of 0.3 cm was observed after water was poured on. This effect of the order of 1 per cent is, however, thought to be due to a slight quantity of radiation reflected from the water surface and not thoroughly screened off from the thermopile.

Water in a thickness of 2 cm is therefore practically completely absorbing for rays emitted by a body at temperatures of 100° C and lower, and would therefore be a perfect radiator at such temperatures, provided its reflecting power for these rays were zero. The reflecting power was determined as follows at Washington:

Using the same arrangement of apparatus the mirror was now made horizontal. For it was now known that any rays reflected must come not from the mirror but from the water surface, since water is opaque to the rays to be observed. Having adjusted the beam from the blackened kettle at 100° C to cause from 4 to 8 cm deflection of the galvanometer, distilled water 1 cm thick was poured on the mirror. The following proportions were obtained for the reflection by water compared to the reflection by the silvered glass mirror. The values depended on the angle of incidence.

TABLE 104.—*Long-wave reflection by water.*

Date.	Deflection, dry mirror.	Percentage reflected by water.	Angle of incidence.
1917.			°
Oct. 27	8.00	8.7	60
	8.56	3.7	38
	6.69	2.8	27.5
31	4.24	20.8	71.5
	5.14	24.7	72.3
	5.07	10.7	73.5
	8.30	5.4	49.5

These results are shown graphically in the plot, figure 43. They indicate that for angles of incidence above 75° the reflection is above one-third total, and that for vertical incidence the reflection of water is approximately 2 per cent for the long-wave rays emitted by a blackened teakettle at 100° C.

We may now determine the departure of a water surface from being a perfect radiator as follows:

TABLE 105.— *Water and the perfect radiator.*

Altitude of emergence	0°–15°	15°–20°	20°–30°	30°–40°	40°–55°	55°–70°	70°–90°
Sine of mean angle	0.100	0.300	0.423	0.574	0.737	0.887	0.985
Mean percentage reflection	50.0	30.0	12.0	7.0	4.2	2.7	2.2
Fraction of hemisphere	.259	.083	.158	.143	.176	.121	.060
Product last three lines above	1.30	.75	.80	.57	.54	.29	.13

Taking the sum of the last line we conclude that water lacks but 4.4 per cent of radiating and absorbing as much as the perfect radiator. Although for considerations of the temperature of the earth's surface there is therefore almost no error in regarding water as if it were a "black body," yet it is not to be forgotten that for angles of incidence exceeding 75° water is highly reflecting. This has no influence on the emission of nocturnal radiation from a level water surface, for the atmospheric vapors cut off all such rays within a few hundred meters of the source. But waves and cloud droplets present many surfaces vertically so that this fact is still of some importance. In later experiments to be described with the honeycomb pyranometer, it was observed that for angles of incidence up to 15°, water at temperatures under 30° C radiates 99.5 per cent as much as the perfect radiator. This agrees within experimental error with the corresponding value, 98 per cent, which results from the values above given near vertical incidence.

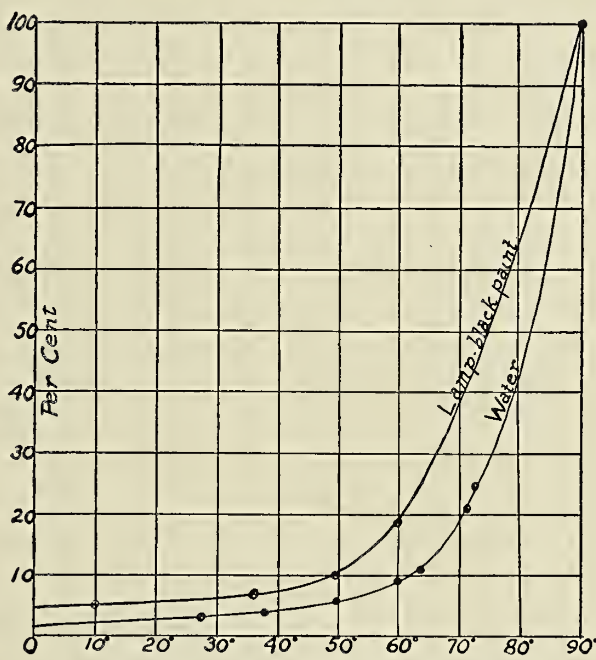

FIG. 43.—Reflection of 100° rays by water and lampblack surfaces.

D. How nearly is lampblack a perfect radiator for long-wave rays?

With similar apparatus to that shown above, Aldrich measured the transmission and reflection of lampblack soot and of lampblack paint made up with alcohol and a little shellac and strained through cheesecloth before applying to surfaces. A silvered glass mirror and a bright aluminum plate were used as reflectors in these experiments. They gave equal reflection for the rays emitted by a blackened teakettle at 100°.

In some experiments a glass plate, unsilvered, was used instead of the silvered glass. In this way a distinction could be made as between a ray transmitted through the blackening material and reflected from the material at the back, and a ray reflected from the surface of the blackening itself. Glass at the angles used reflects only about 10 per cent as much of the radiation as silver. Hence if the reflected ray observed was transmitted by the blackening it should have but a tenth the intensity when the blackening is applied to naked glass that it would have on silvered glass.

In order to test the quality of the reflected and transmitted rays, a polished rock-salt plate 0.6 cm thick was sometimes inserted in the beam. If the rays were of less wave length than 19μ the plate would cut off 7 to 8 per cent by reflection. But if rays of longer wave length than 19μ occurred the plate would cut them off entirely by absorption.

In some experiments a fishtail gas burner was used as a source instead of the blackened teakettle. This showed how much the imperfect absorption of lampblack depends on the wave length of the rays observed. A summary of the results obtained is given in the following tables:

TABLE 106.—*Long-wave reflection of lampblack.*

I. SOURCE: BLACKENED TEAKETTLE AT 100° C.

Angle of incidence.	Reflecting surface.		
	Lampblack paint on silver.	Lampblack paint on glass.	Soot on aluminum.
°	*Per cent.*	*Per cent.*	*Per cent.*
60	18.5	16.3	....
48.5	9.9	9.7	17
36	7.2	6.0	26
10	5.2	....	32

II. SOURCE: THE FISHTAIL GAS BURNER.

°			
35	1.9	1.75	6.8
10	....	1.4	14.0

From these experiments as plotted in figure 43 it would at first appear that lampblack paint reflects almost exactly twice as much of the rays of a 100° blackened teakettle as water does, and that it transmits almost nothing. If these results were both true, lampblack paint would emit and absorb about 91 per cent as much of rays proper to a temperature of 100° C as the perfect radiator. As with water, one must remember, of course, that for rays at high incidence lampblack paint is highly reflecting.

The experiments, however, are not as conclusive for lampblack paint as for water, for unlike water the surface of lampblack paint may be supposed to reflect diffusely as well as regularly. Hence a part of the rays received by reflection from the lampblack paint surface were rays scattered from a considerable area. While it is certain that the values given above are not too great for the total reflection, including both regularly and diffusely reflected rays, they may be too small, because a considerable part of the diffusely reflected rays perhaps did not reach the thermopile.

As shown by the table, candle soot is much different. It evidently transmits a large amount of radiation, both of the comparatively short-wave rays of the fish-tail burner and of the long-wave rays of the blackened teakettle. In order to test this matter further, a rock-salt plate which transmitted 82 per cent of the rays of the blackened teakettle was smoked with candle soot so thick that an incandescent lamp filament was invisible through it. Rock salt and soot together then transmitted 46.6 per cent. Thus the soot itself transmitted 57 per cent. A thicker coat of soot was applied, which was found by weighings to have 0.0002 grams per cm^2. Even this thick coat of soot transmitted 49 per cent. These experiments show how unfit candle smoke is for absorption purposes in long-wave ray experiments, even within the region where rock salt is transmissible.

Another experiment made at this time in the same manner may well be mentioned here. A rock-salt plate was painted with asphaltum, just as Fowle was accustomed to paint his rock-salt prism. Such a coat transmitted 95.6 per cent of the rays transmitted by the rock-salt plate from the blackened teakettle at 100°.

We now return to take up the quality of the rays reflected from various surfaces, as tested by interposing a rock-salt plate in the reflected beam.

TABLE 107.—*Percentage of reflected beam cut off by 0.6 cm plate of rock salt.*

I. SOURCE: BLACKENED TEAKETTLE AT 100° C.

Angle of incidence.	Reflecting surface.					
	Silvered glass.	Glass.	Water.	Collodion on glass.	Lampblack paint on glass or silver.	Candle soot on aluminum.
°						
60	21	23	24	23	21	....
48.5	....	....	....	....	....	36
35	....	....	....	....	....	30

II. SOURCE: FISHTAIL GAS BURNER.

Angle of incidence.	Silvered glass.	Glass.	Water.	Collodion on glass.	Lampblack paint on glass or silver.	Candle soot on aluminum.
°						
35	11.2	15	....	....	23	26
10	....	....	....	....	....	25

In an additional experiment the ray of the teakettle reflected from silvered glass was caused first to traverse a polished rock-salt plate, thus cutting off rays beyond 19μ. A lampblack painted rock-salt plate was inserted and found to transmit only 1.3 per cent. Even this may have been through pinholes. A very thin sheet of carbonized paper transmitted nothing.

From the experiments given in the table, and remembering that the rock-salt plate cuts off 21 per cent of the rays in question, we see that glass, water, collodion, and lampblack paint do not much alter the quality of rays reflected by them from a source at 100° C or less. With the fishtail gas burner, however, a larger part of the shorter wave-length rays is absorbed than of the longer ones by lampblack paint, so that the reflected beam becomes richer in long-wave rays, and a larger proportion is cut off by rock salt. The same holds true for the candle soot on aluminum, and even more with it for the 100° source than for the other. This work shows how inferior candle smoke is to lampblack paint for blackening radiation apparatus.

E. Are there any substances adapted by their transparency for very long-wave rays to be used for prisms and plates in spectrum investigations beyond 17μ?

For these determinations thin plates were prepared from a very large number of natural and prepared crystals very kindly furnished by Dr. G. P. Merrill, of the United States National Museum. Such plates and others we secured were inserted one by one in the front of the Coblentz thermopile. In the following table we give the results of Aldrich's observations with them in the beam from the blackened teakettle at 100° C. In the table R. S. is used to mean rock salt.

TABLE 108.—*Long-wave transparency of various substances.*

Date.	Material as screen.	Per cent transmitted.	Remarks.
Jan. 12	Glass (1.5 mm thick)	1.8	
	Shellac on R. S. plate	34.2	42 per cent of R. S. rays transmitted by shellac.
	R. S. plate	81	
	Paraffin film on R. S. plate	33	41 per cent of R. S. rays transmitted by paraffin.
	Quartz (6 mm thick; no R. S.)	.5	
	Thin sheet black paper	0	
	Thin cover glass	1.3	With R. S. plate, deflection the same.
	Sheet of mica	2	Do.
	Sheet of celluloid	.5	Do.
	Gelatine	3	Do.
	Thin silver chloride, AgCl	17	With R. S. plate 17 per cent of this is cut off.
	Crys. sulphur (3 mm thick)	0	
	Thin flake of shellac	0	
	Flake of iodine	32	17 per cent of this cut off by R. S.
	Do	....	19 per cent of this cut off by R. S.
	Flake of iodine coated with asphaltum (flake 0.5 mm thick).	....	16 per cent of this cut off by R. S.
	R. S. plate	79	
14	Dental rubber (0.2 mm thick)	6	38 per cent of this cut off by R. S.
	Hard rubber sheet (0.14 mm thick)	8	33 per cent of this cut off by R. S.
	Ivory plate (1.4 mm thick)	0	
	Dry ice (about 1 to 2 mm thick)	0	Thermopile and ice outside the building.
	Potassium iodide crystals (1 mm thick)	38	Surface of crystals fairly smooth but interior full of striæ and bubbles; 17 per cent of radiation transmitted cut off by R. S.
15	Thin gypsum, (0.19 mm thick and very clear)	9	5 per cent of this cut off by R. S.
	Barite, $BaSO_4$ (2.5 mm thick)	8	6 per cent of this cut off by R. S.
	Celestite (1.5 mm thick)	8	0 per cent of this cut off by R. S.
	Potassium bichromate, K_2CrO_7 (3 mm thick)	7	10 per cent of this cut off by R. S.
	Colemanite (0.6 mm thick)	4 (?)	
	Sylvite, KCl (3 mm thick)	65	12 per cent of rays transmitted through sylvite cut off by R. S.
	Iceland spar (37 mm thick)	0	
	Wulfenite (0.4 mm thick)	18	10 per cent of this cut off by R. S.
	Rock candy crystals (3 mm thick)	0	
	Potassium alum crystals (1.5 mm thick)	0	
	Nickel sulphate	0	
	Potassium sulphate (2 mm thick)	6	20 per cent of this cut off by R. S. (surfaces ground flat on a file, which probably decreased the transmission).
	Potassium iodide, KI, previously melted (1 mm thick).	30.6	17.7 per cent of this cut off by R. S. This melted KI also filled with striæ and bubbles which probably decreased the transmission.
16	Potassium sulphate crystals (polished with rouge and water but still not good).	8	18 per cent of this cut off by R. S.
	Piece of crystal sulphur	31	10.2 per cent of this cut off by R. S.

Of all these substances only potassium iodide seems at all suitable. Iodine itself to be sure, is transparent beyond where rock salt cuts off, but it is so volatile that there seems no way to employ it for spectrum researches.

During the war several commercial companies developed apparatus for growing great crystals of Rochelle salt. Dr. Whitney of the General Electric Co. very kindly caused efforts to be made to grow large potassium iodide crystals. About a half dozen of these, each of about the size of a 2 centimeter cube, were grown very clear and satisfactory, though yellow. On February 15, 1919, experiments were made by Aldrich on two polished plates of this material. One plate was 2.35 mm, the other 4.6 mm thick.

Of the rays from the 100° C source the thin plate transmitted 84.7 per cent, the thick plate 80 per cent. A rock-salt plate 6 mm thick cut off of the original beam 19.5 per cent. When inserted in the beam with the thin potassium iodide plate it cut off 17.7 per cent. With the thick plate it cut off 15.5 per cent. With no potassium iodide, but another rock-salt plate in the beam, the rock-salt plate cut off 8 per cent, doubtless nearly all by reflection.

Thus potassium iodide transmits rays of considerably greater wave length than sylvite, and we hope to employ the large crystals of it which Dr. Whitney has so kindly caused to be prepared to construct a small prism of 15° refracting angle in order to carry further the work of Fowle above reported.

F. How much of atmospheric humid air is required to cut off the rays of above 18μ wave length which rock salt does not transmit?

A great lampblack-painted copper tank, 90 cm square, 3 cm thick, standing vertically was filled with vigorously boiling water electrically heated and observed with a lampblack-painted tellurium-platinum thermopile at various distances through air of known humidity. In order to keep the angle of the cone of rays unchanged, a limiting diaphragm 8 cm square was placed 120 cm in front of the thermopile. The thermopile was surrounded by a water jacket composed of a long coil of tin pipe containing steadily flowing water. All of this was well wrapped in cotton. In these circumstances, readings were made at 2.15, 4.50, and 12.50 meters from the 100° radiator. A 6 mm thick rock-salt plate was sometimes inserted. In this work as in all the preceding work of Aldrich, the deflections were taken with respect to a metal shutter at air temperature with two plates separated by an air space, bright toward the radiator, and painted with lampblack toward the thermopile.

TABLE 109.—*Aldrich's observations on radiation from 97° C blackened surface.*

Date.	Observed temperature—			Distance.	Galvanometer deflections (each a mean of four).		Per cent radiation cut off by salt plate.	Aqueous vapor, grams per cubic meter.	Precipitable water per meter.
	Of source (water always boiling).	Of thermopile.	Of wet and dry bulbs.		Without salt plate.	With salt plate.			
1918	°	°	°	*Meters*					*cm*
May 25				2.15		362			
					453		20.1		
						361			
					443		18.3		
		21.4				362			
					448		19.4		
						361			
					458		21.0		
						363			
					454		20.2		
						361.5		13.5	0.00135
	97.0		19.0 24.0		453		20.0		
						363			
Means...					451	362			
May 25				4.50		335			
					415		20.2		
						328			
						312			
	97.0		17.6 24.7		392		18.9	11.1	.00111
						324			
Means...					[1] 407	327			
May 25				12.50		294			
					363		18.2		
						300			
			18.9 25.2		362		19.0		
						285			
					356		19.1		
	97.0	22.3				292		14.3	.00143
					372		21.0		
						296			
Means...					363	293			

[1] It is regrettable that only two observations of the full radiation were made at 4.5 meters distance, and these two were rather discordant By comparisons below it seems likely that the first of these two values is best and it is given double weight in what follows.

The following data are prepared from Fowle's observations already summarized and they will be compared with the mean observations of Aldrich to be given below:

TABLE 110.—*Values from Fowle's observations to use for forming a comparison with Aldrich's.*

Wave length.	Relative distribution of energy 373° to 300° K.	Transmission.			
		Cm. precipitable water.			Rock salt.
		0.003	0.005	0.018	
μ					
2-3	25	(.84)	(.82)	(.70)	0.916
3-4	270	.89	.86	.75	.916
4-5	800	.80	.75	.65	.916
5-6	1,300	.88	.80	.60	.916
6-7	1,560	.63	.47	.27	.916
7-8	1,600	.88	.80	.63	.916
8-9	1,480	1.00	1.00	1.00	.916
9-10	1,300	1.00	1.00	1.00	.917
10-11	1,110	1.00	1.00	1.00	.917
11-12	930	1.00	1.00	1.00	.920
12-13	770	1.00	1.00	1.00	.900
13-14	630	1.00	1.00	1.00	.870
14-15	520	(.50)	(.50)	(.50)	.80
15-16	440	(.80)	(.70)	(.60)	.70
16-17	370	.97	(.92)	(.80)	.55
17-18	310	(.90)	(.85)	(.61)	.35
18-19	260	(.90)	(.85)	(.61)	.15
19-20	220	(.90)	(.85)	(.61)	.00
20-α	1,730	(.90)	(.85)	(.61)	.00

From these data of energy and transmission Fowle computed the following values to represent the original energy of the beam exchanged between perfect radiators at 373° and 300° K and the same after absorption by the given quantities of water vapor with and without the interposition of rock salt. These are compared with numbers proportional to Aldrich's mean deflections.

TABLE 111.—*Comparison of Fowle and Aldrich data.*

Distance (meters).	Computed energy.		Observed deflections ×0.306.	
	Without salt.	With salt.	Without salt.	With salt.
0	156	118	....	....
2.15	137	104	138	111
4.50	132	100	125	100
12.50	115	90	111	90

The agreement between observed and computed values is fair, though by no means complete. The rate of decrease of radiation with increasing distance as observed exceeds that computed by Fowle. We are enabled by the comparison to estimate with some assurance how much loss occurred in traversing the first 2.15 meters of moist air. The loss appears to be about 12 per cent. It is thus apparent that it might be objectionable to have more than 5 or 10 centimeters of moist air within a system of apparatus designed to determine accurately the radiation constant between radiators at low temperatures.

Let us now consider the radiation beyond the wave length of 18 μ, which, as Fowle's figures show, is practically all absorbed by the rock-salt plate. First it is necessary to correct the deflections observed with the rock salt for the reflection of the plate, before subtracting them from the full deflections to determine the part beyond 18 μ. Adding about 8 per cent for this purpose we find the following results:

TABLE 112.—*Extinction of long-wave rays.*

Distance	00	2.15	4.50	12.50
Precipitable water, cm	00	.0029	.0050	.0180
Deflection for rays beyond 18 μ	(66)	58	52	45
Deflection for rays less than 18 μ	(454)	393	355	318
Total deflection, all wave lengths	(520)	451	407	363

In all three cases, with the rays as a whole, and with the rays of more and of less than 18 μ in wave length, respectively, the fractional decrease of intensity with increasing quantities of precipitable water as the path in air increases, proceeds more and more slowly with each equal increment of precipitable water. This is immediately seen if the logarithms of deflections are plotted against quantities of precipitable water in the path of the beam. Such a result is quite in line with expectation, because the beam in each case is a complex of many wave lengths, presumably differing in transmissibility. It is therefore impossible to determine accurately from these experiments how long a path of air would be necessary to nearly extinguish the rays. Minimum values may, however, be estimated for rays exceeding 18 μ in wave length. These are as follows:

TABLE 113.—*Extinction of long-wave rays.*

Percentage transmission	88	79	68	50	25	10	1
Precipitable water, cm	.003	.005	.018	.063	.163	.297	.610
Distance if humidity is 0.001 gram per meter	3	5	18	63	163	297	610

From these figures it appears that with ordinary humidity distances of the order of a kilometer would be required to approximately extinguish the outgoing nocturnal radiation from the earth of wave lengths exceeding 18 μ. Half the intensity is, however, extinguished within distances of the order of a hundred meters.

5. THE MELIKERON OR HONEYCOMB PYRANOMETER.[11]

For researches on rays whose wave length exceeds 15 μ, neither smoke, lampblack, nor platinumblack is a perfect absorber. What is worse, the reflecting powers of these substances are not known as a function of the wave lengths. For nocturnal radiation work particularly, it is very desirable to construct receiving apparatus which is fully absorbing by virtue of form independent of such uncertainties of surface texture. Such a receiver is of course, the hollow chamber of Kirchoff or so-called "absolutely black body."

The great difficulty in devising a hollow-chamber receiver for long-wave length rays is the small sensitiveness which such a receiver is likely to have. In other words, the small hole through which the rays come bears so small a proportion to the area of the receiving chamber that the heat of the rays is so much diffused as to make an almost imperceptible rise of temperature. It occurred to Messrs. Abbot and Aldrich to overcome this difficulty by an application of what is generally known as the guard-ring principle. That is to say, by arranging a great number of cells like a honeycomb, the central ones would be protected from the loss of heat around the outside by the presence of their adjoining neighbors, so that the rise of temperature at the central part of the honeycomb would be approximately the same as if it were a strip of metal equal in area to the cross section of the central cells. The area for the loss of heat would be only the front and the back, while the sides would be protected from such losses. In the design of the instrument for the purposes of measurement, we adopted the principle of the Ångström pyrheliometer. That is to say, we proposed to compensate for the heating effect of the rays upon the honeycomb by the introduction of a current of electricity equally distributed over the honeycomb.

In order to accomplish this, the honeycomb itself was made of a long ribbon of very thin "therlo" metal about 12.5 mm wide and 0.02 mm thick. This ribbon, nearly a meter long, was bent into triangular flutings, alternating with straight portions, as shown in the figure. Each corner of each triangular fluting was insulated by a narrow streak of shellac baked onto the metal. The whole ribbon was bent up in a square honeycomb of about 200 cells, each 2.2 mm on a side. The central cells of the honeycomb were provided with four thermoelectric junctions joined in series and situated, respectively, 2.5, 5, 7.5, and 10 mm from the front surface. Thus they gave together a fairly distributed indication of the temperature of the central cells of the honeycomb. The other ends of the four thermoelectric junctions were inserted in the brass casing of the apparatus. This brass casing, however, was separated from the honeycomb itself by a small air space

[11] See also L. B. Aldrich, The Melikeron—An Approximately Black-Body Pyranometer. Smithsonian Miscellaneous Collections, vol. 72, no. 13.

across which there were placed thin silvered-glass mirrors with knife-edges so as to confine the honeycomb to its square area, but to carry off very little heat from it by conduction. As the corners of the cells were insulated, the one from the other,

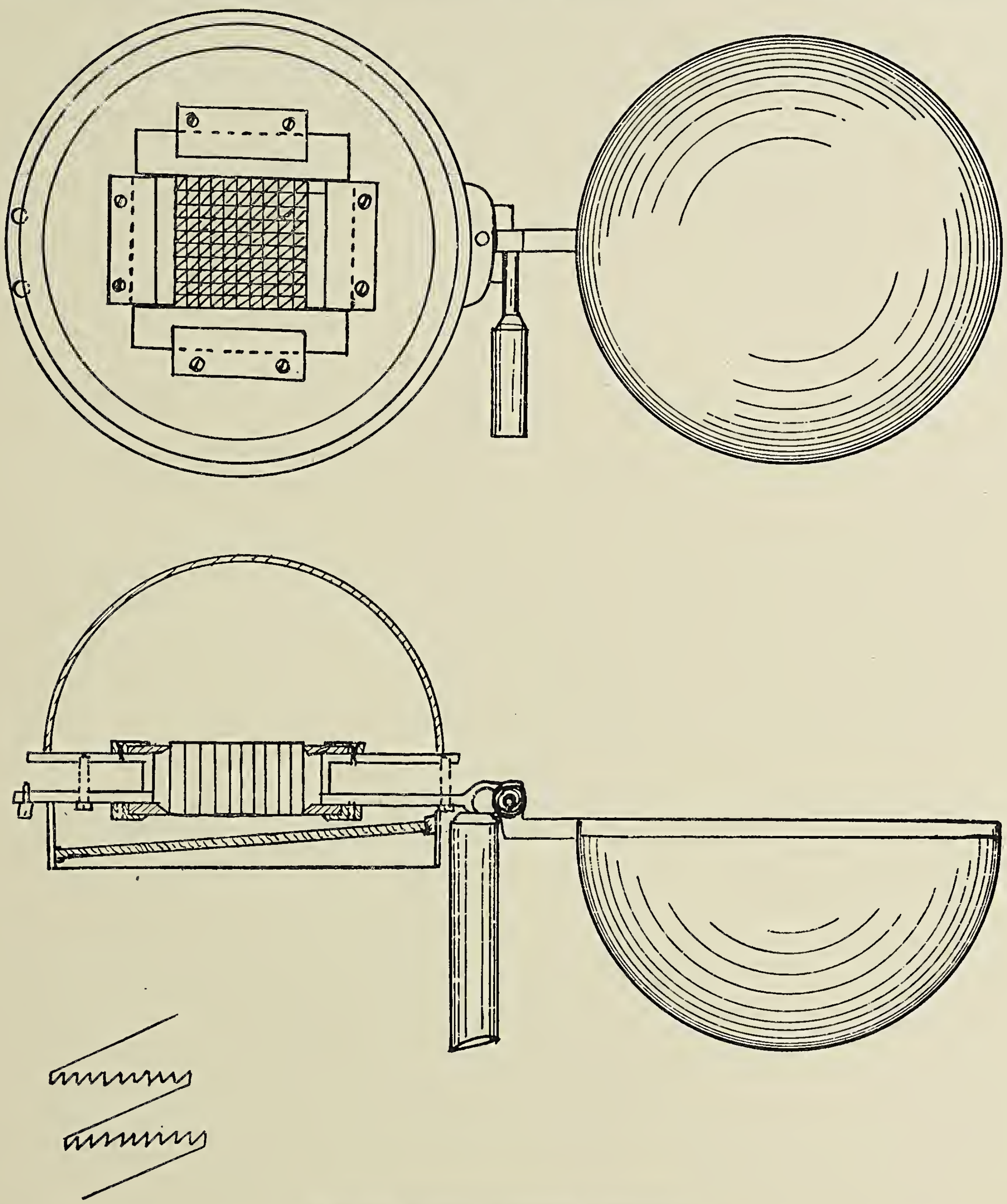

Fig. 44.—The melikeron or honeycomb pyranometer.

a current of electricity could pass through the whole length of the ribbon and would be distributed substantially in the same manner as the heat received by radiation.

The first instrument which was constructed in this way by Mr. Aldrich naturally cost a great deal of effort. Indeed, the construction of such instruments must necessarily be a very tedious process, owing to the great care required for bending without cutting the ribbon and for insulating the cells. In the first construction we used manganin ribbon 0.04 mm thick, and this is not to be recommended because the actual cross section of the ribbon itself bears a proportion to the whole area of the order of 6 per cent. However, the edges of the ribbon, being cut with a knife, are naturally inclined to the surface and apt to reflect the rays which reach the front down into the recesses of the cells. Thus even in instrument No. 1 the correction for reflection by the edges of the ribbon was not very great. In order to increase the effective depth of the cells, a silvered glass mirror was placed just behind the rear surface of the instrument. In the first construction this mirror was placed parallel to the back face. It is better to incline it at an angle of 5° so that the rays which are returned will not fail to be reflected against the sides of the cells. The lower two-thirds of the cells were blackened by dipping in a thin mixture of lampblack in turpentine. The upper one-third was left shiny so as to reflect the rays to the interior of the cells and thus tend to equalize the distribution of the radiation.

The first instrument had the following constants: Electrical resistance of therlo strip, 0.945 ohms; area of cross section of the honeycomb, 5.83 cm^2; correction for areas of small triangular shape at edges, 0.30 cm^2; corrected area, 5.53 cm^2. From these figures the constant of the instrument by which the square of current strength is to be multiplied to give calories per cm^2 per minute was computed to be

$$\frac{0.945\times 60}{4.185\times 5.53}=2.45.$$

In order to test the apparatus it was compared with the ordinary flat-surface pyranometer. In this test the honeycomb instrument was covered with an optically figured hemispherical glass screen 7.5 cm in diameter. Under glass the constant is to be increased 8 per cent, becoming 2.66. The instruments being substituted the one for the other in exactly the same central positions underneath an electric lamp, they were read alternately and the intensity of the radiation of the lamp computed with each according to the constants which were proper to it. These comparisons were made with a carbon-filament electric light, and also with a "daylight" tungsten electric light, and at different altitudes above the horizontal. The results of the comparisons follow. (See Table 114.)

From these results it appears that the honeycomb pyranometer and the flat strip pyranometer read substantially identically except for rays coming within 7° of the zenith. For these rays, as was to be expected, the silver mirror at the back of the honeycomb reflected a portion directly back without being absorbed. The angle of the cone in which this partial loss of radiation occurred does not appear to be more than 5° from the zenith, and even in this small area the absorption of the radiation by the honeycomb is not less than 85 per cent. Accordingly the loss of radiation from this cause over a whole hemisphere will not amount to much more than one part in a thousand. For rays coming vertically, however, from a small angular aperture the loss is proportionately greater. In a second construction this loss was almost wholly avoided by inclining the reflector as above mentioned.

TABLE 114.—*Comparison of melikeron and pyranometer.*

Conditions.	Calories by melikeron No. 1.	Calories by pyranometer No. 5.	Ratio, melikeron / pyranometer.
Carbon lamp:			
60 cm above; 0° incidence	0.0538	0.0648	0.830
60 cm above; 25° incidence	.0522	.0537	.972
"Daylight" tungsten lamp:			
30 cm above; 4½° incidence	.0435	.0512	.850
30 cm above; 7½° incidence	.0502	.0517	.972
30 cm above; 13° incidence	.0558	.0562	.995
8 cm above; 72° incidence	.0245	.0237	1.033

APPLICATIONS OF THE HONEYCOMB PYRANOMETER.

In order to test thoroughly whether the instrument was satisfactory for long wave-length work, its first application was to determine approximately the constant "sigma" by observing with it the radiation of perfect radiators at different temperatures. For this purpose two large metal inclosures were made as shown in figures 4 and 5 of Aldrich's publication just cited, and these placed side by side with stirred water at different temperatures within their walls. The first intention was to place the honeycomb pyranometer in a wooden sheath and lower it down through the necks of the black chambers alternately so as to expose it to a whole hemisphere. Unfortunately on trial this proved to be impracticable. The conduction or convection of the gas within the colder chamber instantly cooled the honeycomb, so that this kind of cooling being superposed upon the cooling by radiation, the apparent constant "sigma" was found to be double the true value. In order to avoid this source of error, a water-circulated vestibule, with accurately measured aperture of 1.82 cm radius and constantly maintained temperature, was introduced 7.03 cm below the honeycomb and the whole was surrounded by cotton insulating material and placed upon the top of the neck of the radiator. Under these circumstances the first rough approximate expression for the constant "sigma" became as follows:

$$\sigma = 2.45\left(\frac{7.03}{1.82}\right)^2 \cdot \frac{C^2}{(T_1^4 - T_2^4)}.$$

In order to keep the temperatures of the apparatus as constant as possible, a rapid current of water was caused to flow through the vestibule wall. Thick wrappings of cotton were also employed. The exposures to the different radiators were made by moving the apparatus from one to the other. For this purpose the honeycomb and accessories were mounted on an arm swinging on a vertical axis.

Preliminary experiments in this way yielded promising results. Still it was feared that a remnant of error due to direct air cooling of the diaphragms of the water jacket might remain. In order to test this, five thermal junctions were placed, respectively, against the five diaphragms of the vestibule of the honeycomb pyranometer and connected in series with a galvanometer through 100 ohms resistance. Under these circumstances a change of 1° C in the temperature of the diaphragms produced 3 cm deflection of the galvanometer. The second junctions of the thermopile were then packed within the cotton wrapping close against the outer wall of the water-jacket vestibule. Thus, if so much as 0.001° C change of temperature of the diaphragms occurred on exposure to the cold "black body" it would be easily observed.

Several experiments were made with the honeycomb pyranometer after the manner just described, which yielded the following results: T_1 and T_2 are absolute temperatures of the radiators, dt the fall of temperature of the diaphragm walls on passing from warm to cold radiator, C the compensating current of the honeycomb pyranometer, and σ the preliminary value of the constant sigma as observed.

Table 115.—*Observations on "sigma."*

Date.	T_1.	T_2.	dt.	C.	σ
1920.	°	°	°	*Amperes.*	
Mar. 24	301.31	273.40	0.04	0.0765	8.07×10^{-11}
25	292.63	273.44	0.025	0.0617	7.99×10^{-11}

Each of these values is the mean of seven closely agreeing individual determinations.

Certain corrections must be applied to the preliminary value of "sigma." We will suppose that since the thermal junctions attached to the diaphragms were at the most exposed points as regards air cooling, the whole inside of the vestibule is to be regarded as having fallen in temperature only through the amount $\frac{dt}{2}$, and we assume, what is sufficiently true to determine a small correction, that the lampblacked inner surface of the vestibule is a perfect radiator. Then, since the aperture of the vestibule subtends but $\frac{1}{30}$ hemisphere, while of course the radiation of the vestibule is subject to the law of cosines, the correction proper to allow for the changed intensity of the radiation going out from the honeycomb to the vestibule as compared that with going out to the radiator is the following proportion:

$$\frac{29}{4}\frac{dt}{(T_1-T_2)}$$

This correction of about 1 per cent is to be applied to diminish the resulting value of sigma.

Another correction is to be applied for the imperfect absorption and radiation of rays near vertical incidence. If we admit that the magnitude of this correction is determined by the observations above given on sources radiating mainly in the shorter wave lengths, to be, however, increased with proper regard to the angular aperture of the vestibule as compared to a hemisphere, it becomes approximately 1.8 per cent. This correction is to be applied to increase sigma.

A third correction depends on the extended surfaces of the honeycomb and of the aperture. As the latter is of 1.82 cm radius, the aperture as seen from the center of the honeycomb face subtends a fraction of a hemisphere: $1-\cos(\tan^{-1} 0.2589) = 0.0320$. On the other hand, the area of the circular aperture, $\pi\ (1.82)^2$, compared to the area of the hemisphere, $2\ \pi\ (7.03)^2$, is 0.0335. Hence an increase of 4.5 per cent is to be applied to sigma for this correction. It does not appear to be necessary to apply a corresponding correction for the extended surface of the honeycomb itself, because the outer parts of it act merely as a sort of guard ring about the inner central parts where the thermal measurements are made, and the fact that the radiation from the outer parts is diminished by 2 or 3 per cent by increased distance from the aperture can not sensibly alter the temperature of the central cells.

Another correction might seem to be required to allow still further for the imperfect absorption of the honeycomb. This depends on two causes; first, the fact that the cross-section of the ribbon amounts to 6 per cent of the total exposed surface. Being rough and beveled in cutting, the outgoing reflection could not, however, nearly reach this figure. Secondly, some radiation received near the mouth of each cell is likely to be diffusely reflected out again at the front without absorption. But similar corrections should have been applicable in the comparisons already reported between the melikeron and the pyranometer. Inasmuch as these experiments indicated agreement to within experimental error between these instruments, with the constants heretofore assigned to each for all rays except those near normal incidence (already taken into consideration), we shall suppose that the indentations along the edges of the melikeron were not exactly allowed for, or that in some other way a counterbalancing change was made in the theoretical computed constant of the melikeron, so that the above suggested correction is unnecessary in view of actual agreement with the pyranometer when using the computed constant.

On the whole, then, the first approximate value of σ is to be increased by $(1.8+4.5-1.0)$ or 5.3 per cent. Our mean value then becomes:

$$8.49 \times 10^{-11} \text{ calories per cm}^2 \text{ per minute.}$$

Mr. Fowle gives 8.26×10^{-11} in the Seventh Revised Edition of the Smithsonian Physical Tables.

Thus it appears that the melikeron, which agrees closely with the Smithsonian standard pyrheliometric scale as reproduced by pyranometer No. 5, when exposed to short-wave radiation transmissible by glass, is also in fairly close accord with the best work published when used to measure radiation of great wave lengths.

Melikeron No. 2, which will be found described more fully in Mr. Aldrich's publication above cited, has been compared several times without glass cover in sunlight along with silver-disk pyrheliometers. The comparisons were made by allowing the melikeron to come to its full temperature rise near noon under direct or slightly inclined constant sun rays such as shine on fine days at Mount Wilson and Mount Harqua Hala. A constant state of temperature being reached, as shown by the constancy of the galvanometer deflection, the sunlight was cut off and instantly compensated by electric current of the proper intensity. The mean of several solar comparisons between the melikeron No. 2 and various standardized silver-disk pyrheliometers gave 4.00 as the constant of the melikeron. The theoretical computed constant, after allowing as well as possible for indentations along the edges, reflection by the edge of the ribbon and other corrections, is 4.05. This melikeron shows a defect of about 6 per cent for parallel rays at strictly normal incidence, but none above 7° incidence.

Melikeron No. 2 was compared by day and by night with pyranometer No. 5 at Mount Wilson, by day in sunlight by comparing both instruments with the pyrheliometers, and by night with each other directly on nocturnal radiation. The constant found by day for melikeron No. 2 as above stated is 4.00. The constant found by day, September 1, 1920, for pyranometer No. 5 (without glass) was 22.75. Using the above given melikeron constant as correct also for nocturnal rays, the nocturnal constant found for pyranometer No. 5 by comparison with melikeron No. 2 on September 1, 1920, is 24.25. Readings of the wet and dry thermometers at this time were 56° and 71° F., respectively. If we assume that the blackened strip of the pyranometer absorbs 98 per cent for sun rays, it follows from these results that it absorbs but 92 per cent for nocturnal rays when the humidity and other conditions were as occurred on the evening of September 1, 1920, on Mount Wilson. In our paper on the pyranometer we made the assumption that 95 per cent of nocturnal radiation would be absorbed. This appears to be too high a value. In other words, enough rays occur of great wave length, for which lamp-black paint is a very imperfect absorber, to diminish the absorptive power of the pyranometer strip from 98 to 92 per cent.

Comparisons have been made on many occasions between melikeron No. 2 and Ångström pyrgeometer No. 22. They appear to indicate that the absorbing and radiating properties of the pyrgeometer vary with weather conditions, and differ also from the values indicated by Dr. Ångström's calibration of the instrument. Further observations are needed to settle these matters.

Chapter IX.

UTILIZATION OF SOLAR ENERGY.

A. SOLAR RADIATION FOR POWER PURPOSES.

It has been many times suggested that, as the sun furnishes so much energy and indeed is the source, primarily or secondarily, of nearly all the available energy in the world, suitable devices could be invented to employ it directly for furnishing power. Many experiments have been made along these lines. Mr. A. G. Eneas, for example, constructed a large mirror which he employed at Pasadena and in New Mexico for some years, but of this he wrote:

As a result of my experience with about nine different types of large reflectors, I believe: (1) That with similar mirrors perfected in details about 3.90 British thermal units per square foot per minute (1.06 calories per square centimeter per minute) would be the greatest amount of heat obtainable at noontime in Arizona and other cloudless regions of similar latitude, (2) that better progress in utilizing solar heat commercially for power can be made along lines described in the Engineering News of May 13, 1909. But the actual obtaining of any great amount of power from solar rays is still an unsolved problem.

The figures given indicate a loss of about one-third of the available solar heat in collection. Thermodynamics and engine efficiency have still to be reckoned with.

About the same time Messrs. H. E. Willsie and J. Boyle, jr., carried on some experiments on the utilization of solar radiation for power purposes at Needles. These experiments and those of Mr. Eneas are described at some length in Abbot's "The Sun," page 367. So far as we are aware, such experiments have been abandoned in the United States.

At about the same time, Mr. Frank Shuman conducted experiments somewhat similar to those of Messrs. Willsie and Boyle near Philadelphia, and later a British company was formed to employ his methods for the utilization of solar radiation in pumping plants in Egypt. The results are described by A. S. E. Ackermann in the Smithsonian Report for 1915, page 141, from which the following summary is quoted:

This plant, Shuman says, ran well even when snow was lying on the ground. This at first seems very remarkable, but though in the winter the number of solar rays falling on a given horizontal area is smaller than in summer, the permeability of the atmosphere is about 20 per cent greater in winter than in summer, which partly counteracts the other effect; but of course the loss of heat by conduction from the boiler is greater in winter than in summer.

In 1910 Shuman constructed an experimental unit of an absorber measuring 6 by 9 feet. This unit combined the lamellar boiler of Tellier and the "hot box" of de Saussure, for it consisted of a shallow black box with double glass top, with 1 inch of air space between the two layers of glass, another air space of an inch between the lower glass and the boiler, which was 6 feet long (up the slant), 2 feet 6 inches wide, and ¼ inch thick over all. The box was so sloped that at noon the rays of the sun were perpendicular to the glass. The box was not moved to follow the sun, but it was adjusted about every three weeks, so that the condition just named was complied with. The remarkable thing about the absorber was that there was no concentration of any kind of the sunshine by mirrors, lenses, or other means, and yet the author on one occasion recorded a temperature of 250° F. in the box. The best run of an hour's duration produced steam at atmospheric pressure at the rate of 7½ pounds per 100 square feet of sunshine falling on the box. The author's tests of a Shuman 100 horsepower low-pressure engine at Erith showed the steam consumption to be 22 pounds at atmospheric pressure per brake horsepower hour. Hence, with an absorber of the type just described, it would be necessary to collect solar radiation to the extent of 300 square feet per brake horsepower, which is a much larger area than any named by other workers. The maximum thermal efficiency of this absorber was 24.1 per cent.

In 1911, with the aid of some English capitalists, Shuman constructed his third absorber at Tacony (a suburb of Philadelphia), which was almost identical with the one just described, except that it had two plane mirrors, one at the upper edge of the "hot box" and one at the lower, so arranged that 6 square feet of sunshine were concentrated onto 3 square feet of "hot box"; i. e., the concentration was 2 to 1. Its position was adjusted about every three weeks. This time the total quantity of solar radiation collected was many times as large as the largest collected by any previous worker, for the total area was 10,296 square feet. In the best run of one hour this plant produced 816 pounds of steam at atmospheric pressure. This at the rate of 9 pounds per 100 square feet of sunshine, and therefore equivalent to an allowance of 245 square feet of sunshine per brake horsepower. The maximum thermal efficiency of this absorber was 29.5 per cent (fig. 45).

Toward the end of 1911 the Sun Power Co. (Eastern Hemisphere) (Ltd.), requested their consulting engineers (Messrs. A. S. E. Ackermann and C. T. Walrond) to select and invite some distinguished physicist to join them in a consultative capacity. Hence Prof. C. V. Boys, F. R. S., became associated with the work, and he suggested a vital change in the design of the absorber, viz, that the boilers should be placed on edge in a channel-shaped reflector of parabolic cross section, so that solar radiation was received on both their surfaces, instead of one being worse than idle, as it was when the boilers were placed side on to the sun. The design immediately received the hearty approval of the consulting engineers and Shuman, and at the time we all thought the arrangement was novel, but the author has since found and recorded herein that Ericsson used a very similar reflector and boiler.

An absorber of this design was constructed and erected at Meadi on the Nile, 7 miles south of Cairo, in 1912, but the boiler was constructed of thin zinc and failed before the official tests could be made. This boiler was replaced by a cast-iron one in 1913, and the author (accompanied by his old pupil, G. W. Hilditch, A. M. Inst. C. E., as his chief assistant, now Lieut. Hilditch of the Divisional Engineers, Royal Naval Division) spent two most interesting months with the plant in July and August, 1913. He went out in time to tune up the Shuman engine (a 100-horsepower one) taken out from Tacony, and make all the necessary preparations for the trials, of which there were over 35.

In addition to the alteration of the shape of the reflectors, another very important change was made. Their axes were placed north and south, and they were automatically heeled over from an eastern aspect in the morning to a western one in the evening, so as to follow the sun. Thus the same number of solar rays were caught all day long, and the small decrease in steam production in the morning and evening was almost entirely due to the greater thickness of atmosphere through which the rays had to pass. The total area of sunshine collected was 13,269 square feet (figs. 46 and 47).

The boilers were placed at the focus of the reflectors and were covered with a single layer of glass inclosing an air space around the boilers. Each channel-shaped reflector and its boiler was 205 feet long, and there were five such sections placed side by side. The concentration was 4½ to 1. The maximum quantity of steam produced was 12 pounds per 100 square feet of sunshine, equivalent to 183 square feet per brake horsepower, and the maximum thermal

Fig. 45.—General View from the West of Shuman Absorber, Tacony, 1911.

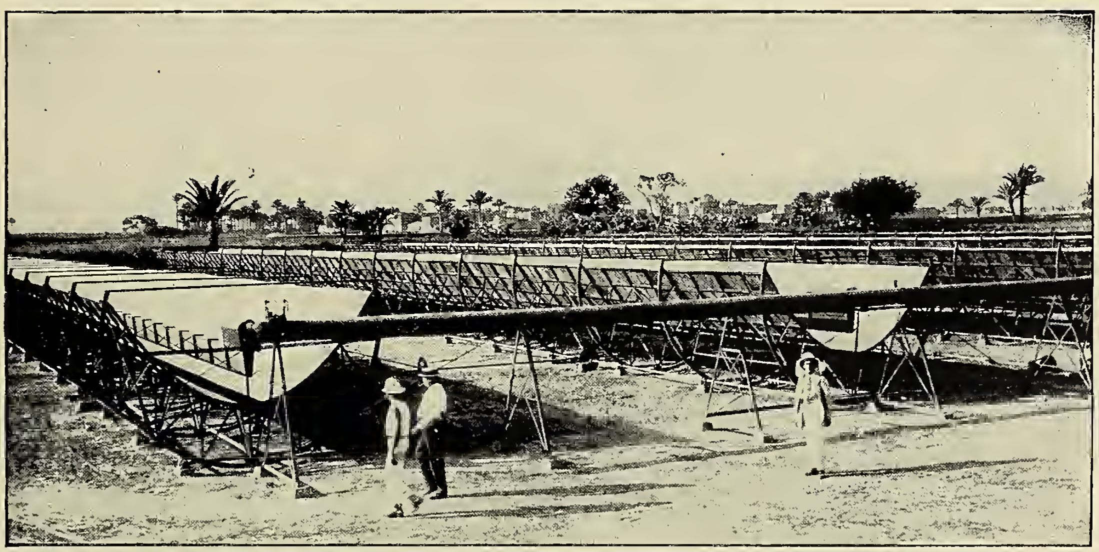

Fig. 46.—General View from the South of Shuman-Boys Absorber, Meadi, 1913.

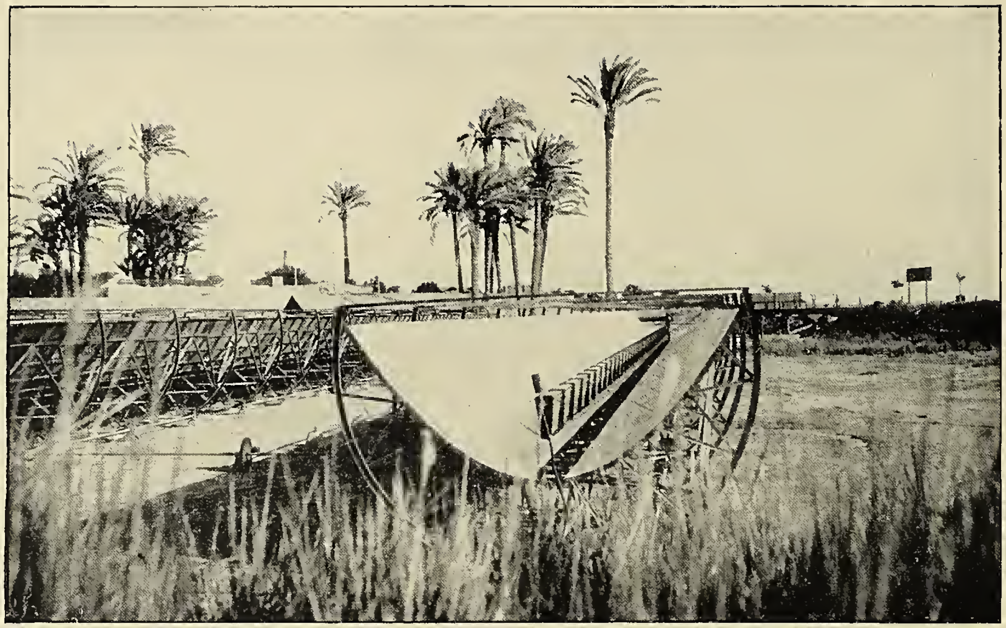

Fig. 47.—Shuman-Boys Absorber, Meadi, 1913. One Section of the Absorber from the North.

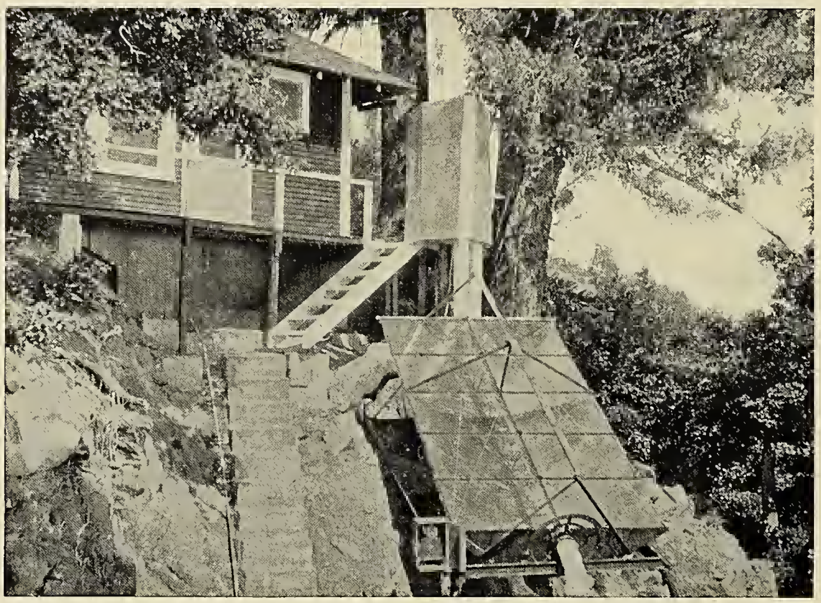

Fig. 48.—The Great Mount Wilson Solar Cooker.

efficiency was 40.1 per cent. The best hour's run gave 1,442 pounds of steam at atmospheric pressure, hence, allowing the 22 pounds of steam per brake horsepower-hour, the maximum output for an hour was 55.5 brake horsepower, a result about 10 times as large as anything previously attained, and equal to 63 brake horsepower per acre of land occupied by the plant. A pleasing result was that the output did not fall off much in the morning and evening. Thus on August 22, 1913, the average power for the five hours' run was no less than 59.4 brake horsepower per acre, while the maximum and minimum power on that day were 63 and 52.4 brake horsepower per acre, respectively.

We are not aware whether this interesting plant is still in operation.

In all these attempts to use the solar radiation for power purposes the grave difficulty is not that there is a lack of energy in the solar beam, but that it is spread over a relatively large space and that it is interrupted by night fall during half of the time and by clouds during a considerable portion of the remainder. Morever, while the sun is above the horizon, its heating effect, if gathered on a horizontal surface, as in the experiments of Messrs. Willsie and Boyle at Needles, is variable with the cosine of the zenith distance of the sun, besides being diminished near the horizon by the great thickness of the intervening atmospheric layer. Thus, the radiation to be absorbed is so variable in amount and the space over which it is received is so considerable, that the first cost of proper appliances for the collection and regulation of the power is very large, although the subsequent cost of operation is small. Hitherto these drawbacks have prevented sun power from competing with power of coal, gasoline, and flowing water, but it is possible that some happy idea may yet be thought out which will overcome these handicaps.

B. SOLAR RADIATION FOR COOKING PURPOSES.

In the use of solar heat for cooking purposes it is only necessary to attain a certain suitable temperature and maintain it for a considerable length of time in order to do the desired work. While it is a difficult thing to retain heat as compared with the difficulty of retaining electricity, yet by cheap insulating materials applied in sufficient quantity the heat of a large reservoir of fluid may be retained with moderate loss for considerable periods of time. Hence the variability of the solar radiation may be counteracted on the same sort of principle as the variability of certain engines is counteracted by flywheels. That is, if the heat obtained from the sun in the favorable times is stored in a large well-protected reservoir it may be conserved to cover those unfavorable periods which are sure to occur.

The employment of solar radiation for domestic purposes is practiced to some considerable extent in southern California in this way: A portion of the roof of the building is covered with glass and beneath it there are placed appropriate water reservoirs connected with the water circulation within the house, and during a bright day the reservoirs under the roof reach a temperature sufficient to warm the water for bathing purposes.

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EARLY EXPERIMENTS.

A promising experiment on the use of solar radiation for cooking purposes is described by Mr. W. Adams, of Bombay, India, in the Scientific American, June 5, 1878. The arrangements which he used and the results achieved are described as follows: The eight-sided conical concentrator was made of wood lined with silvered glass. It was hinged upon a board and adjusted by a wedge and by rotating the board so as to face the sun. The position of the apparatus required to be changed about once each half hour. The cooking vessel of copper was inclosed in a glass case and fixed to the back of the concentrator. Mr. Adams stated that the rations of seven soldiers, consisting of meat and vegetables, were thoroughly cooked by it in a couple of hours, in January, the coldest month of the year in Bombay; and that the men declared the food to be cooked much better than in the ordinary manner. The dish is stewed or baked, according as the steam is retained or allowed to escape.

About 1910, experiments were begun by Smithsonian observers at Mount Wilson to employ solar radiation for the heating of water. A concave parabolic cylindric mirror about 3 feet wide and 4½ feet long was supported by an equatorial mounting so that the axis of the parabolic cylinder was at right angles to the axis of the earth, and the mirror could be tilted to the east in the morning and moved occasionally with the sun through the day, and could also be tilted toward the north in the summer and toward the south in winter, to follow the change of declination of the sun. The complexity of these necessary adjustments required a flexible circuit to bring in the water which was designed to be heated by this mirror. This was accomplished by introducing a spiral tube of many turns at the foot of the polar axis, and a similar one at the head of it, so that one spiral would be somewhat twisted and the other somewhat untwisted as the mirror was faced toward the east or toward the west. Having reached the rectangular frame within which the declination axis of the mirror was placed, the water circuit passed around this frame to the side and continued on around the frame of the mirror and passed to and fro many times through a reservoir of oil made of a 6-inch tube, nearly of the length of the mirror, which was well protected by a layer of cotton and asbestos. Beyond this reservoir the upper spiral tube led the water to a cock where it might be drawn off for domestic purposes. The mirror itself was composed of a large number of sheets of ordinary looking-glass, each sheet 1 inch wide, laid upon the steel parabolic frame so that although no regular curve was made, yet the reflections of the different facets of the mirror collected on the inch and a half blackened tube in the focus very satisfactorily. Within this tube, and connecting pipes, and the reservoir above mentioned, circulated oil.

In order to prevent currents of air from cooling the tube, and to act in some measure on the principle of the gardener's hotbed, a flat sheet of glass was laid over the whole mirror. Also as the steel frame of the mirror became considerably heated, owing to the convection of the air within the mirror, the rear of the frame was covered with a layer of cotton and asbestos.

The device worked on the whole in an interesting manner and furnished a bucket of hot water near the boiling temperature every two or three hours, but it could hardly be regarded as more than a toy, though we employed the water for bath and domestic purposes. The complexity of the double motion of the apparatus and the necessity of leading in the water circulation by flexible tubes worked against the success of it, although the fact that the axis of the mirror was at right angles to the polar axis obviated the necessity of giving a regular continuous motion to the mirror itself from east to west.

THE GREAT SOLAR COOKER ON MOUNT WILSON, CALIFORNIA.

In view of the results obtained in this particular experiment, a larger mirror was designed in 1915 to work upon another plan. The motion of the sun in declination from north to south was to be neglected. The mirror was to be placed with its axis parallel to the axis of the earth and rotated to follow the sun by appropriate clockwork. Thus the tube on which the rays of the mirror were to be collected could be fixed once and for all parallel to the axis of the earth, and so the flexible connections of the liquid circuit could be avoided. This required the introduction of approximately accurate mechanism for rotating the mirror from east toward west. A very simple and cheap method of doing this was devised.

Referring to the accompanying illustration, figure 48, the large wheel shown at the foot of the polar axis is connected by a piece of piano wire to a weight which continually tends to turn the mirror toward the west, but the motion toward the west is continually restrained by another piano wire leading over the wheel to a cheap Seth Thomas motor movement such as was used formerly, before the general use of electric motors, for rotating models in show windows. This motor movement, located in the little box to the west of the wheel, as shown in the illustration, is provided with a fly vane so that one rotation of its central wheel takes place in about two minutes. If, then, the weight which tends to turn the mirror toward the west were allowed to drive the motor movement continuously, the mirror would race so fast as to be ahead of the sun, and would, perhaps, reach the sun's western position by midday. In order to regulate and restrain this excessive rate of motion an ordinary alarm clock is provided having at the rear on its central shaft a wheel of 12 pins, each pin corresponding to five minutes of time. A suitable lever and ratchet device is arranged between the alarm clock and the motor movement, so that each pin in succession trips the starting mechanism, allows the lever connected with the central shaft of the motor movement to make one complete rotation, stops the movement at that point, where it remains until the next arriving pin of the alarm clock sets off the works again. Thus the mirror is caused to rotate from east toward west, not, to be sure, perfectly uniformly, yet so nearly so that during the whole course of a day the image of the mirror falls upon the tube at its focus.

The scheme of conserving the heat collected by the mirror is as follows:

Above the level of the top of the mirror is an iron reservoir of about 40 gallons capacity, inclosed in a thick layer of nonconducting material composed of asbestos, cotton, and wood, and protected on the outside from the weather by a case of galvanized iron. In this reservoir are two ovens, entered from the north by first opening the door of the insulating case and then opening the iron doors of the ovens. These iron doors are upon horizontal hinges and let down, like the door of a gas stove, until they form an extension of the floor of the oven.

The reservoir is filled with gas-engine cylinder oil of high boiling point, and has three $2\frac{1}{4}$-inch pipes leading to it from the top, the middle, and the bottom, respectively. The top pipe is bent down to enter the upper end of the mirror, and the middle and lower pipes joining at the outside of the bottom of the reservoir lead down underneath the mirror and come in at its lower end. Within the mirror frame, in the mirror focus parallel to the earth's axis, is a straight pipe which completes the circulation. This pipe is $1\frac{1}{2}$ inches in diameter and forms the polar axis of the machine. The actual bearings of the mirror, however, are roller bearings supporting trunnions, so that the mirror is very free to turn to follow the sun. The pipe passes through the hollow trunnions.

All parts of the oil circulation outside the mirror are wrapped with a thick layer of nonconducting material, mainly cotton, and the mirror itself is covered on the back with layers of cotton and galvanized iron. The top of the mirror is covered with sheets of glass to prevent the wind and the dust from coming in, and the tube which lies in the focus of the mirror is covered with 3-inch glass tubes so as to cut off convection currents and retain the absorbed heat in the immediate vicinity of the tube of oil.

The reader will at once understand the principle of the device, for it is the same as that which is in common use in cooking stoves and furnaces to provide hot water for domestic purposes. In other words, the heat which is absorbed within the mirror expands the oil in the tube and tends to make it rise, so that the hot oil is continually entering at the top of the reservoir and the cooler oil flowing from the bottom of the reservoir under the back of the mirror, and so on continuously.

Another feature is introduced to take into consideration the different temperatures required for different kinds of cooking, and to take account also of the cooling of the oil which occurs when the sun is obscured by clouds or at night. A valve is provided within the reservoir, so that the circulation may take place either through the tube at the middle of the reservoir or through the tube at the bottom of the reservoir, as desired. An automatic control for this valve is provided by means of a float so that during the first part of the heating of the reservoir the circulation takes place through the pipe at the middle, leaving the lower part of the oil unaffected, but when a certain temperature is reached the oil in the reservoir, having expanded, raises the float, and changes the valves, thus causing the circulation to flow from the lower tube. The effect of this is to concentrate the heat in the upper part of the reservoir when the latter is too cool and to automatically extend the volume of heating after the upper part has become sufficiently hot. The further effect of it is to cause the upper oven to be the hotter and the lower of a medium temperature. Provision is also made for cutting off the circulation entirely at night, so as to prevent the apparatus from reversing itself by diffusion so as to lose heat gained in the day by flow of the oil to the relatively cool pipe within the mirror during the long sunless hours of night. A coil for heating water circulation is placed between the iron reservoir and its insulating covering.

The mirror itself, 10 feet long, 7 feet wide, was made up of structural steel in 5 sections each 2 feet in length. Each section was framed by a pair of L-shaped members bent to the form of a parabolic bow and its string. On the front of each pair of curved L-irons was fastened a thin sheet of smooth steel which itself, if it were polished, would accordingly have formed a mirror, but as this would have been a very poor reflector, it was proposed to cover the steel sheets with sheets of tin-foil and this experiment was first tried. Owing to an unfortunate leakage of oil which occurred at a certain joint in the pipe, the tin-foil became very dirty before the end of the experiments, but this was not the most serious trouble. It was found that no suitable means of fastening the tin-foil to the sheets of steel could be arranged. For as the mirror became heated, as the experiments went on, the tin-foil puffed up in blisters all over the surface and so spoiled the definition of the mirror. Accordingly, the preliminary experiments, although very promising, were not satisfactory for the reason that no suitable mirror surface had been provided. An order was accordingly given for sheets of polished aluminum, somewhat thicker than the tin-foil, to take its place, but the exigencies of the war prevented the aluminum (which reflects about 75 per cent) from being used for several years.

In the preliminary series of experiments, temperatures of the order of 130° C were obtained in the oil reservoir. Cooking was regularly carried on with vegetables, meats, and the like, and the ovens were employed for the warming of toast, and for other convenient purposes for the table, but not sufficiently high temperature was had for the baking of bread, owing to the defect of the mirror above mentioned. The experiments, however, seemed to demonstrate that with the improved surface of the mirror no trouble at all would be found in doing any culinary operations except frying with the device. In its present form, no doubt, the apparatus would be too large and costly to be practicable, but it was believed best to make it on a large scale so as certainly to meet the requirements of the problem from a heat standpoint, and then if the experiment proved successful it might be that sufficient economies could be made to adapt it for practical use in desert countries.

The cost of the experiments was defrayed in part by grants from the National Academy of Sciences and the American Academy of Arts and Sciences.

In the year 1920, the experiments were resumed at Mount Wilson. The polished aluminum sheets which had been ordered in February but received in October, 1916, too late for use that year, were screwed on to the parabolic steel backing to serve as a mirror surface. Their reflecting power was measured by fastening a piece of aluminum sheet to a flat board and attaching it as a mirror to the coelostat. Two observers then read two pyrheliometers, the one close to and pointed at this mirror, the other pointed directly at the sun. The mean of 5 pointings to different parts of the mirror indicated its average reflecting power as 77.3 ± 2.2 per cent. It will be recalled that four years had already elapsed since the sheets were rolled. It may be remarked that in several months use of them in the hot mirror, no apparent change appeared in them. Some loss of heat occurred by imperfect figure of the aluminum mirror surface so that a small proportion of the rays reflected shot by on the sides of the oil tube. This proportion, though it could not be measured accurately, seemed small, perhaps 10 or 15 per cent at most.

Recalling that the mirror was covered by window glass only fairly clean, as it could not be continually kept in the condition of a lens or prism, we may set the transmission of it at 85 per cent. Further recalling that the oil tube was protected by a glass tube, another loss of 15 per cent may be admitted for it. Within this glass was the lampblack-painted tube whose absorption may be set at 95 per cent. Recalling further that no provision was made for the motion of the sun in declination, so that the mirror was right only on the equinoxes, a small loss occurred at the mirror ends by rays not reaching the mirror surface and reflections not reaching the tube. This diminution of the effective size of the mirror varies with solar declination. An average value for it is 5 per cent. A great loss, not a feature of the instrument but of its location, was due to the shade of trees that could not well be removed. This practically cut off all sun rays after 1 o'clock in the afternoon, besides producing a little shade in the early morning, and thus amounted to a loss of about 40 per cent during the day.

Summing up the seven transmissions:

Glass.	Aluminum.	Glass.	Focus.	Blackening.	Declination.	Shade.	
85 ×	77 ×	85 ×	85 ×	95 ×	95 ×	60	= 25.6 per cent.

It thus appears that only about one-fourth of the sun's heat available during the day was collected to warm the oil. Of course the shade of the trees was absent much of the time. The factor would then rise to 43 per cent. The loss at focus could be avoided by more accurate construction, and perhaps means could be found to keep the glasses clean enough to raise their transmissions to 90 per cent. It would be impracticable to substitute silver on front of glass for the aluminum, and silver on back of glass reflects but little better than aluminum besides being costly, heavy, and fragile. Hence we may set the maximum attainable efficiency at

$$90 \times 77 \times 90 \times 95 \times 95 = 56 \text{ per cent.}$$

Of this possible maximum efficiency, by neglecting the tree's shading, we attained 77 per cent.

We shall now inquire what maximum average temperature of the reservoir containing the ovens ought to be expected in consideration of the income and outgo of heat. Allowing for the frames supporting the glass, the cross section of the solar beam was about 60,000 cm^2. Let us suppose a maximum oven temperature would be reached before the shade of the trees came on, which in fact was nearly attained. Of the incoming beam of about 1.50 calories per cm^2 per minute at noon, 43 per cent or 0.645 calories is supposed to be absorbed in the oil. Total heat absorbed by the oil, 38,700 calories per cm^2 per minute.

The iron reservoir, $40 \times 40 \times 120$ cm outside has approximately 20,000 cm^2 area. It is protected from wind by its galvanized iron case, and from heat conduction by 10 cm of boxwood and 10 cm of cotton wool, moderately compressed, on every side. The wood in this thickness conducts about 0.000040 calories per second, the cotton about 0.000009 calories per second [1] for 1° C temperature difference over the surroundings. Hence the two combined would conduct about 0.0000075 calorie per cm^2 per second per 1° C temperature difference. Total loss by the reservoir per 1° C is then 0.150 calorie per second or 9 calories per minute per 1° C temperature difference over the surroundings. This does not take into account the loss of heat through the doors of the ovens by their cracks and actual opening to receive or remove cooking. The cracks were well listed, the doors triple, one iron and two wood and cotton, so that this loss was small except when the doors were actually opened.

The $2\frac{1}{2}$-inch oil tube leading from the mirror to the reservoir and return was exposed for a length of 800 cm. Its exposed area was accordingly about 16,000 cm^2. It was protected by $2\frac{1}{2}$-cm thick magnesia-asbestos and outside of this by 7-cm thick cotton wool moderately compressed surrounded by a galvanized-iron pipe. The conductivity of these insulations combined is about 0.000010 calorie per second per 1° C, so that for the whole pipe the loss would be about 9.6 calorie per minute per 1° C temperature difference.

Besides this, there are 300 cm of $1\frac{1}{2}$-inch pipe within the mirror protected only by the air spaces, glass tube, and glass cover. The area here is about 3,600

[1] Smithsonian Physical Tables, 7th edition, p. 216.

cm². It is difficult to treat these heat losses, and perhaps it may be done most conveniently by regarding the large mirror space as the outside surroundings and the pipe as protected from them by 0.4 cm thick glass and 2 cm thick air space. The conductivity across this system may be set at about 0.003 calorie per second per 1° C, so that the total loss for the tube within the mirror may be set at about 650 calories per minute per 1° temperature difference over the air of the mirror.

The impossibility of protecting the tube within the mirror by efficient insulation leads to great losses relatively to its area, and we see the important advantage of the glass tube and glass cover, even though they cut off about a fourth of the solar rays. If it were practicable to create a high vacuum between the glass tube and the oil tube this loss could be greatly reduced. During the night and cloudy days it is fortunately cut off entirely. Its magnitude is diminished by raising as high as possible the temperature within the mirror. This was done by protecting the back of the mirror frame by 2 cm thick of cotton wool inclosed by galvanized-iron backing. Thus the air within the mirror grew very hot, approximating 100° C.

Without actually computing the maximum expected oven temperature from these data, it will be more convenient to see how they agree with recorded temperatures. On September 4 to 6, 1920, three thermoelectric couples were employed, one soldered to the oil tube within the mirror near its upper end, one within the upper oven in the reservoir, the third in the lower oven. On the two latter of these days the solar radiation reached at maximum about 1.45 calories per cm² per minute. As usual the ovens were in constant use for baking, stewing, warming of water, canning of fruit, or the like. In the following table are given the observed temperatures at various times from 7h 5m p. m. on September 4 to 5h p. m. on September 6.

TABLE 116.—*Temperatures in great solar cooker.*

Time.	Centigrade temperatures.			
	Upper oven.	Lower oven.	Oil tube.	Air.
h. m.	°	°	°	°
Sept. 4 7 5 p. m.	111	80	60	23
5, 6, 0 a. m.	88	75	20	19
7 5	90	79	108	20
7 45	90	78	128	22
9 10	118	76	145	25
10 10	132	77	155	27
12 10 p. m.	142	84	160	27
[1] 1 35	149	102	152	27
6 10	121	101	72	23
Sept. 6 6 0 a. m.	90	86	....	19
12 m.	136	88	161	27
1 5 p. m.	143	90	164	27
5 0	121	94	74	25

[1] Shaded.

The maximum oven temperature observed on these days was 149° C. On some previous days, mercury thermometers within the upper oven had reached 155° C or about 128° C above the surroundings. It is evident from the figures given that had the shade of the trees not interfered higher temperatures would probably have been attained.

As it is, about half of the reservoir was 122° above the surroundings, the other half 75° above them. The return tube was, we will assume, 115° above them. The tube within the mirror was, we will assume, 60° above the air in the mirror. In these circumstances, according to our previous data, the rates of loss expected will be:

	Calories per minute.
Reservoir	985
Return tube	1, 104
Oil tube in mirror	39, 000
Total	41, 089

This expected loss somewhat exceeds the supposed income, which at 1.45 calories outside the mirror would amount according to our data to but 37,500 calories. The small discrepancy is to be expected from the roughness of our data. Probably we have overestimated slightly the loss from the oil tube within the mirror.

At first sight the reader will think the design very bad that would trouble to cut down the rate of loss from the reservoir and return to dimensions so insignificant compared with the inevitable loss within the mirror. But one must reflect that the former losses, or at least that from the reservoir, go on all night and on cloudy days to the cooling of the ovens, while the loss within the mirror stops at dark. It is interesting to compute how nearly the nocturnal cooling of the reservoir corresponds to expectation.

From September 5 at 6:10 p. m. to September 6 at 6 a. m., 710 minutes, the upper oven cooled 31°, from 121° to 90°, and averaged during this interval 83° above the air. The lower oven cooled 15°, from 101° to 86°, and averaged 71° above the air. Taking out the oven volumes and the upper 10 centimeters of the reservoir not filled with oil, the capacity for heat of the reservoir is approximately equivalent to 70,000 grams of water. Of this about 0.3 cooled 31° and 0.7 cooled 15°. Thus the total loss of heat from the reservoir was approximately 1,400,000 calories in 710 minutes. If half of the reservoir was 83° and the other half 71° above the air, the average rate of loss according to previous data would be 693 calories per minute, making 560,000 calories lost by conduction during the night. In addition will be losses by diffusion of the oil, by leakage of air at the oven doors, and by communication of heat from the reservoir into the wooden case, which doubtless continued to rise in temperature during the early part of the night. The agreement between expectation and actual occurrence, while not close, is not after all very bad considering the roughness of the data.

PERFORMANCE.

The tests of the oven in actual cooking operations were carried out exclusively by Mrs. Abbot, though watched with interest and envy by other ladies. All varieties of baking were highly successfully done, though requiring somewhat longer time than ordinary, owing to the rather low oven temperature. Cooking of meats and vegetables was exceedingly satisfactory. The preparation of cereals for breakfast dishes required no attention after the start, as the dishes would be hot and smoothly cooked at breakfast time. The canning of fruit and vegetables was very easy. Pared fruit with sirup would be placed in cans, and set into the lower oven over night. In the morning it required only to clamp the covers of the cans. As the apparatus was just outside the door of the kitchen all the oppressive heat of summer cooking was avoided, although but a few steps were required to go out with the dishes. Hot ovens available without running expense through the entire 24 hours were regarded very favorably by all visitors. The water-heating circulation, which was designed to be connected to the gravity water supply, alone proved a failure. Not sufficient conductivity existed through the wall of the reservoir and the long coil of lead water pipe to heat the water anywhere near boiling while it was running through the coil even slowly. The coil should have been inside of the reservoir for this purpose.

On the whole the experiments with cooking by indirect solar heating have been successful, although in the light of experience great improvements could be introduced. Dwellers in cloudy sections and in large cities could not use it. At all stations, unless the reservoir were made many times larger, which would add to the cost, auxilliary cooking applicances for cloudy weather would be needed.

SUMMARY.

The principal features of the present volume are as follows: 1. The continuation for nine years of investigation of the intensity of solar radiation, as it is at the earth's surface, and of its intensity outside the atmosphere. 2. New determinations of the solar constant of radiation by two methods, that of Langley, based on high and low sun observations of homogeneous rays carried through about 1,300 times at three stations since 1912, and that of observing the sun's total radiation at altitudes progressively higher and higher, from sea level to high mountain stations and up to 25,000 meters as reached by sounding balloon observations in 1914. 3. Further tests of the errors of solar-constant observations by the method of high and low sun, including besides theoretical and statistical studies, two successive days of spectrobolometric work from the moment of sunrise till nearly noon, with air masses ranging from 18.8 to 1.3. 4. The installation and prosecution for eight years of observations of the distribution of radiation over the sun's disk. 5. The establishment of additional solar radiation stations at distant points for the purpose of checking and confirming the evidences of solar variability. 6. The introduction of a new short method of solar-constant determinations based on the Langley method of high and low sun, but requiring only 15 minutes for all the observations. 7. The comparison of the independent results of far-separated stations, and the correlation with solar-constant values of our own studies of distribution of radiation over the solar disk, and of the observations reported by others on terrestrial temperatures and magnetism, on the number of sun spots, and on the brightness of the planets. 8. The extension of our hypothesis of solar variability to contemplate a sun radiating with variable intensity according to the prevailing solar activity, but its radiation also modified by the prevailing local obscurations of the solar envelope and constrained to give the appearance of rapid variability by the solar rotation which brings to the different heliocentric longitudes successively the rays unequally emitted in successive local solar regions. 9. The design and construction of new apparatus for solar and allied researches, including the balloon pyrheliometer, the pyranometer, the vacuum bolometer with complete mathematical theory, the melikeron or honeycomb pyranometer, and others. 10. The investigation of radiations of great wave length in their relations to transmission by water vapor, carbon dioxide, and ozone, and the relations of many common solid substances to these long-wave rays. 11. The measurement of the brightness of the sky under a great variety of circumstances. 12. The determination of the reflecting power of clouds by balloon observations.

It is found that the average value of the solar constant of radiation from 1,244 determinations in the years 1912 to 1920 is 1.946 calories (15° C) per square centimeter per minute. This value exceeds that, 1.933, determined in the years 1902 to 1912 as published in Volume III of these Annals. This excess is attributable to the higher average numbers of sun spots which prevailed in the later period A result indicated by the work published in Volume III is definitely confirmed, namely: Increasing solar activity as shown by increased sun-spot numbers tends toward increased solar radiation. This conclusion must, however, be modified by the effects of local obscurations of the sun's surface, which not infrequently diminish the solar constant, accompanying the passage of great sun-spot groups centrally over the sun's disk.

While the measurements have been conducted mainly at Mount Wilson, California, the station Calama, Chile, occupied from July, 1918, to July, 1920, by Messrs. A. F. Moore, director, and L. H. Abbot, assistant, furnished the most continuous and accurate series of solar-constant values ever observed.

These Chilean observations, telegraphed daily to Buenos Aires at the request of the Argentine weather bureau, have been employed by Mr. H. H. Clayton, Argentine chief forecaster, for several years in forecasting Argentine weather conditions. Mr. Clayton has made a great study of the dependence of weather conditions on solar variation, and believes that solar radiation studies furnish a valuable forecasting element.

With a view to test this supposed dependence of terrestrial weather on solar variations, the Mount Wilson solar-constant apparatus has been removed to a new station, Mount Harqua Hala, Arizona, and the Calama outfit has been installed on Mount Montezuma, Chile. These changes were made possible by the generosity of Mr. John A. Roebling. It is proposed to carry on the solar-radiation observations for several years on all suitable days at these cooperating observatories located, respectively, in the most cloudless regions of North and South America.

APPENDICES

Appendix I.

NEW EVIDENCE ON THE INTENSITY OF SOLAR RADIATION OUTSIDE THE ATMOSPHERE.*

By C. G. ABBOT, F. E. FOWLE, and L. B. ALDRICH.

The following investigations were suggested by several criticisms of the work of the Astrophysical Observatory on the "Solar Constant of Radiation." We shall show (1) that on fine days at Mount Wilson there is no observable systematic change of atmospheric transparency from the moment of sunrise to about 10 o'clock, and (2) that the intensity of solar radiation even at 24 kilometers (15 miles) altitude, at less than one twenty-fifth atmospheric pressure, falls below 1.9 calories per square centimeter per minute.

It will be useful to preface the paper by a brief account of our earlier work. We shall draw attention also to various facts tending to support the result heretofore obtained, namely: The mean value of the "solar constant" is 1.93 calories per square centimeter per minute.

SUMMARY OF EARLIER WORK.

In Volume III of the Annals of the Astrophysical Observatory of the Smithsonian Institution, we published the methods employed, the apparatus used, and results obtained in determinations of the mean intensity of solar radiation outside the atmosphere during the years 1902 to 1912. The method employed was that of Langley.[1] It requires measuring the intensity of the total radiation of the sun with the pyrheliometer and also the measurement of the intensity of the rays of the different wave lengths with the spectrobolometer. Measurements of both kinds are made repeatedly during a clear forenoon or afternoon from the time when the sun is low until it becomes high or vice versa. In this way we determine how rapidly the rays of the sun as a whole and of individual wave lengths in particular increase in intensity as their path in air diminishes. From this we estimate the total intensity of the solar radiation outside the atmosphere altogether.

There are certain parts of the spectrum where by reason of powerful selective absorption of rays by water vapor and other terrestrial atmospheric vapors and gases sufficiently accurate atmospheric transmission coefficients can not be determined in this manner.[2] This offers no great difficulty, for, with Langley, we assume that these absorption bands would be absent outside the atmosphere. Hence the

*Reprinted from Smithsonian Miscellaneous Collections, vol. 65, No. 4.

[1] "Report on the Mount Whitney Expedition," Professional Papers, Signal Service, No. 15, pp. 135 to 142, and Table 120, values 1 to 5.

[2] Investigations of Fowle showed, however, that transmission coefficients can be obtained even in the great infrared bands of water vapor, whose employment would practically obliterate the bands outside the atmosphere. Hence we may conclude that if there are diffuse atmospheric bands not easily recognizable, they will be almost exactly allowed for by ordinary transmission coefficients. See Smithsonian Miscellaneous Collections, vol. 47.

intensity of these parts of the spectrum outside the atmosphere can be determined by interpolation from the intensities found on either side of them.

Whatever the value of the atmospheric extinction of solar rays, all good solar-constant work depends on accurate pyrheliometry expressed in standard calories.

During the investigation we devised two forms of standard pyrheliometer on quite different principles. These instruments agree with each other to within 0.5 per cent, and they yield values of the solar radiation ranging from 3 to 4 per cent above those found with different copies of the Ångström pyrheliometer. This latter instrument was adopted as the international standard for the measurement of radiation by the meeting of the International Meteorological Committee held at Southport in the year 1903 and by the International Union for Solar Research at its meeting at Oxford in the year 1905. Mr. A. K. Ångström has, however, lately pointed out that the Ångström instrument is subject to slight errors which cause it to read about 2 per cent too low, according to his opinion. If so, this brings the scale of the Ångström within less than 2 per cent of the scale of the Smithsonian Institution. The latter scale is fortified by the fact that in our several standard pyrheliometers it is possible to introduce and determine test quantities of heat. This has been repeatedly done in each of these instruments, and the test quantities of heat have been recovered to within 0.5 per cent.

The following table gives the results of nearly 700 measurements of the solar constant of radiation as published in Volume III of the Annals above cited:[3]

TABLE 1.—*Mean solar radiation outside the atmosphere.*

[Expressed in standard 15° calories per square centimeter per minute at mean solar distance.]

Station.	Washington.	Bassour.	Mount Wilson.	Mount Whitney.	Total.
Years	1902–1907	1911–1912	1905–1912	1909–1910	....
Altitudes (meters)	10	1,160	1,730	4,420	....
Observations	37	82	573	4	696
Mean result	1.968	1.928	1.933	1.923	1.933

[3] We note here the following errors which have been found in Vol. III of the Annals, partly by ourselves, and partly by others who have kindly communicated them:

Page 119, figure 11, Nov. 8 misplotted. Should be 2.004, see p. 105.

Page 129, Table 42, November, 1908, for 1.947 read 1.961. Under "Mean," for 1.936 read 1.945.

Page 130, figure 16, November, 1908, for 1.947 plot 1.961.

Page 132, Table 43, fourteenth column, for 592 read 607; for 1,338 read 1,363. Sixteenth column, for −4.4 read −6.6; for −2.1 read −3.9.

Page 134, Table 44, in 1908, for 1.936 read 1.945; in "Total," for 1.9315 read 1.9333. Under "General mean," for 1.932 read 1.933.

Page 138, Table 47, wave lengths, for .5995, .7200, .8085, .9215, 1.0640, 1.1474, 1.2230, 1.3800, read .5980, .7222, .8120, .9220, 1.0620, 1.1460, 1.2255, 1.3770.

Page 162, Table 58, we withdraw the conclusion based on this table as to the direction of the change of distribution of solar radiation with change of "solar constant." A great body of as yet unpublished experiments leads to modifications.

Page 201, table. Under "Intensity," for 1,338 read 4,160.

In regard to the matter mentioned by Kron (Vierteljahr. Astron. Gesell. 49 Jahr., p. 68, 1914), we included in our statement, p. 127, two days of 1911 in which the Bassour work was very satisfactory, but the Mount Wilson work was not. We regret the errors in our figure 15 mentioned by Kron. The principal one is the omission of Aug. 31. Two others are misplotting the Mount Wilson values for Sept. 4 and Sept. 9. All the corrections improve the appearance of figure 15. See p. 122 for the true values.

The Washington results fall a little higher than the others. This may be due, in part at least, to the fact that most of them were made while sun spots were numerous, for our investigations at Mount Wilson indicate that high values prevail when sun spots are at a maximum.

Our determinations rest on the assumption that for all excellent days the atmosphere may be regarded without sensible error as made up of layers, concentric with the earth, which may differ in transparency from layer to layer in any gradual manner, but which, within the time and space covered by a solar beam during a single morning of observation, are for each layer by itself sensibly of uniform trans-

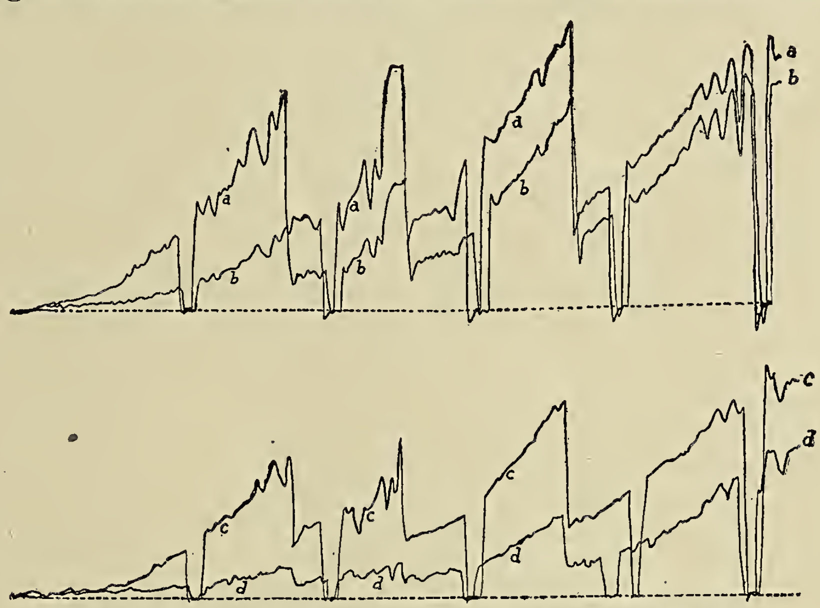

FIG. 49.—Illustrating atmospheric extinction on a clear day and on a hazy day.

Curve *a*, Bassour, June 9, 1912, air mass, 1.5.
Curve *b*, Bassour, June 9, 1912, air mass, 3.5.
Curve *c*, Bassour, July 26, 1912, air mass, 1.6.
Curve *d*, Bassour, July 26, 1912, air mass, 3.5.

parency. As the relative transparency of the several layers is not assumed to be known, it is convenient to limit the duration of a single series of observations to the time interval during which the solar zenith distance is less than 75°. During this interval the rate of decrease of path of the solar beam in the atmosphere, with decreasing solar zenith distance, is sensibly the same in all the supposed atmospheric layers, and is proportional to the change of the secant of the zenith distance. For greater zenith distances than these this proportionality does not hold, because of the influences of curvature of the earth and of atmospheric refraction.

Figures 49 and 50, and Table 2, show something of the variety of conditions of observation encountered; first, as regarding the intensity of sunlight at the observing station; second, as to the effect of atmospheric humidity on the infra-red spectrum; third, as to the effect of dust upon the visible spectrum. We draw attention to the close agreement of the solar-constant values obtained in these contrasting circumstances of observation.

TABLE 2.—*Variety of conditions of observation.*

Place.	Barometer.	Date.	Temperature.	Atmospheric water vapor pressure at station	Precipitable water.[1]	Radiation observed, zenith distance 60°.	Transmission coefficient, wave length λ=.5μ.	Corrected solar constant.
	cm.			*mm.*	*mm.*	*Calories.*		
Washington..........	76.5	Feb. 15, 1907....	3.0	1.45	4.8	1.352	0.837	1.872
		May 14, 1907....	29.0	14.60	22.6	0.939	.626	2.034
Bassour..............	66.3	June 9, 1912....	14.0	6.94	12.6	1.302	.855	1.903
		July 26, 1912....	26.0	5.36	11.9	0.960	.684	1.915
Mount Wilson.......	62.5	Aug. 21, 1910....	23.0	7.39	22.5	1.198	.852	1.933
		Aug. 21, 1911....	23.0	2.50	11.2	1.370	.843	1.944
Mount Whitney.....	44.7	Sept. 3, 1909....	1.0	1.97	(0.90)	1.560	.905	1.951
		Aug. 14, 1910....	2.0	2.05	0.60	[2] 1.607	.923	[2] 1.923

[1] Determined by Fowle's spectroscopic method, and gives the depth of liquid water which would result if all the atmospheric water vapor above the station should be precipitated. Experiments of 1913 show close agreement of this method in its results with those obtained for the same days by integration of humidity observed at all altitudes by sounding balloons.

[2] This value is corrected as suggested in note 2, Annals III, p. 113.

From the foregoing the reader may see that the soundness of the theory of the atmospheric extinction of radiation employed by us is supported by the fact

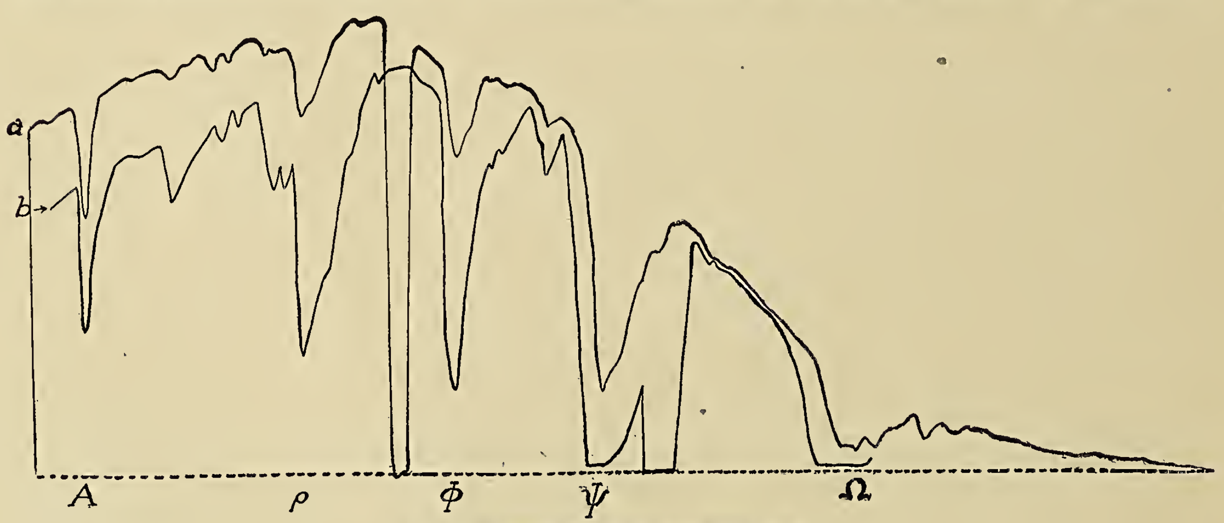

FIG. 50.—Illustrating absorption of water vapor.

Curve *a*, Mount Whitney, Aug. 15, 1910. Secant $Z=1.08$.
Curve *b*, Washington, May 14, 1907. Secant $Z=1.29$.

that its application to observations made under widely diverse conditions yields nearly identical values of the intensity of solar radiation outside the atmosphere. Nevertheless, it is maintained by some critics that our estimate of the atmospheric extinction is less than half large enough. It seems very singular that a grossly erroneous theory, according to which, however, the transmission coefficients of the atmosphere for green light are found to vary in different circumstances from 0.63 to 0.92, should nevertheless correlate its errors in such a way that all these diverse values of transmission coefficients should lead to equal values of the intensity of solar radiation outside the atmosphere.

In further support of our values of atmospheric transmission, we call attention to their connection with Lord Rayleigh's theory of the scattering of light by molecules and particles small as compared with the wave length of light. According to this the exponent of scattering varies inversely as the fourth power of the wave length, and thus the product of fourth power of wave length by logarithm of transmission coefficient should be constant. As shown by one of us,[4] the coefficients of atmospheric transmission obtained on Mount Wilson depend slightly on the total atmospheric humidity included between Mount Wilson and the sun. The transmission coefficients may be reduced to dry air conditions by applying a very small correction to them. These corrected coefficients, a_0, are found to be in close harmony with Lord Rayleigh's theory, as is shown by the following table. The observed values of a are means for September 20 and September 21, 1914:

Wave length λ in μ.....	0.3504	0.3709	0.3974	0.4307	0.4753	0.5348	0.5742	0.6858	0.7644
Observed transmission a	.610	.671	.744	.786	.851	.892	.893	.950	.969
Corrected transmission a_0	.632	.686	.752	.808	.863	.898	.905	.959	.979
$\lambda^4 \log a_0$..............	−30.0	−31.1	−30.9	−31.8	−32.7	−38.2	−46.7	−40.3	−31.4

The deviation from a constant ratio in the yellow and red spectrum is doubtless due to the very large number of atmospheric absorption lines in this part of the spectrum.

By the aid of Lord Rayleigh's theory of the scattering of light, Mr. Fowle has determined from the Mount Wilson experiments the number of molecules per cubic centimeter of dry air at standard temperature and pressure. He finds the value $(2.70 \pm 0.02) \times 10^{19}$, while Millikan obtained, by wholly dissimilar methods, $(2.705 \pm 0.005) \times 10^{19}$.

In the course of our experiments at Mount Wilson we found the solar radiation outside the atmosphere variable in short irregular periods of from 5 to 10 days, and to have a variable range of from 2 to 10 per cent. That this variability is really solar was confirmed by independent simultaneous observing at Bassour in Algeria and still more recently by as yet unpublished experiments on the distribution of brightness over the sun's disk. This latter method is quite independent of atmospheric disturbances. It seems to us that if our solar-constant results were erroneous to the extent that the solar constant is really 3.5 calories instead of 1.93, as some of our critics would persuade us, the probability of finding these real solar variations of from 2 to 10 per cent by simultaneous observing at stations separated by one-third of the circumference of the earth would be very small. We should suppose that if there are atmospheric conditions which lead to our underestimating by nearly 50 per cent the intensity of solar radiation outside the atmosphere, these would probably be variable from day to day; so that such minute real changes

[4] F. E. Fowle, Astrophysical Journal, 38, 392, 1913; 40, 435, 1914.

of the total intensity of the sun's radiation as we have found would have been swallowed up in the irregular local fluctuations of the transparency of the atmosphere.

CRITICISMS OF THE WORK.

We turn from this summary of the work and the circumstances which heretofore indicated its validity, to a discussion of the criticisms which have been made of it by several authors, and the new experiments we have made to refute them. We take the following summaries of objections from several recent articles:[5]

1. Mr. F. W. Very remarks that there are several reliable actinometers, capable, when properly handled, of giving results correct to 1 or 2 per cent, but that unfortunately some of them may give results 20 per cent in error when inefficiently used or imperfectly corrected. Although Mr. Very says in another place that our determinations rest upon perfected instruments and admirable care, yet he has seemed to indicate by his praise of values of the solar radiation obtained from observations on the summit of Mount Whitney, which reached 2 calories per square centimeter per minute, that he perhaps considers our results to be 15 per cent too low, because in three different years we have never observed on Mount Whitney values exceeding 1.7 calories per square centimeter per minute.

2. It is pointed out that we employ the equation[6]

$$\log R = m \log a + \log A$$

as the equation of a straight line. In this equation R is the intensity of one wave length of radiation at the station; A, the corresponding intensity outside the atmosphere; m, the air mass, and a the coefficient of atmospheric transmission, assumed as constant. If log a only apparently, not really, is constant, our results are wrong. Both Mr. Very and Mr. Kron indicate pointedly that they believe log a is not constant, but that in fact the transparency of the atmosphere continually diminishes during the forenoon periods we have chosen for our observations, so that our transmission coefficients are too high, and our value of the solar constant too low on account of this source of error. Mr. Kron indicates possible errors of the solar-constant values of not more than 5 per cent as due to this cause.

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[5] F. W. Very, Astrophysical Journal, 34, 371, 1911; 37, 25, and 31, 1913; American Journal of Science, 4th series, 36, 609, 1913; 39, 201, 1915; Bulletin Astronomique, xxx, 5, 1913.

F. H. Bigelow. Boletin de la Oficina Meteorológica Argentina, 3, 69–87, 1912; American Journal of Science, 4th series, 38, 277, 1914.

E. Kron, Vierteljahrsschrift der Astronomischen Gesellschaft, 49, 53, 1914.

[6] As pointed out by Radau, Langley, and others, this equation is applicable only to homogeneous radiation—that is, radiation of approximately a single wave length. It is always with this limitation that we employ it in our definitive solar-constant determinations. We have, however, pointed out that for a limited range of two or three air masses good observations of total solar radiation, when plotted thus logarithmically, deviate so slightly from the straight line that the smallness of the deviations is a useful guide to the excellence of the observing conditions. In such applications to pyrheliometry we recognize, however, that A would not be the solar constant. In this connection see figure 51, in which, although for a range of 20 air masses there is a steady and well-marked curvature in the plot of pyrheliometry, any range of only two air masses shows this but little. We, therefore, fail to see how Mr. Very's emphatic criticism of our procedure in this respect, which he gives in the French article above cited, is justified.

It appears, however, that Mr. Very attaches great weight to this second objection, for he says of the work of Abbot, Fowle, and Aldrich:

> The neglect of diurnal variation of atmospheric quality, and the erroneous supposition that the same coefficients of transmission can be used at all hours of the day, completely vitiate these reductions.

Again he says:

> The Smithsonian observations, for example, usually stop when the air mass becomes as large as 3 or 4 atmospheres. Some do not even extend to 2 atmospheres. Reduced by Bouguer's formula these midday readings agree among themselves, but solely because they have stopped before reaching the point where disagreement begins. This is equivalent to shirking the difficulties, and the seeming extraordinary agreement of the measures is misleading. If the missing readings had been supplied, the discrepancies would have been obvious. Such incomplete observations are incapable of elucidating the laws of atmospheric absorption except through the aid of more perfect measures. By supplying deficiencies under guidance of a criterion we may in some cases rescue observations which are otherwise useless.

Again he says:

> The portion of the diurnal curve between the limits of 4 and 10 atmospheres conforms tolerably well to the conditions needed for a determination of its slope and general form, and, as a rule, it would seem to be the best part of the curve to select for computation.

3. Mr. Very states that we adopt too high a value of the absorption of terrestrial radiation by water vapor and too low a value of its absorption of solar radiation.

4. We suppose the layers of air to differ gradually from one to another in transparency. This, according to Mr. Very, may be true for some atmospheric elements, but there are others which are sharply restricted to definite layers or other definitely formed volumes, so that the ordinary air-mass formula fails for this cause.

5. A considerable amount of solar radiation is said by Mr. Very to be definitely lost to measurement in the atmosphere. The Smithsonian observations, he says, give merely the quantity *A—B*, where *B* represents the absorption occurring in fine lines of atmospheric origin, or radiation cut off by particles too gross to diffract the rays, or that which is arrested by bands of absorption not composed of fine lines, but large and diffused, and incapable of being distinguished certainly amidst the crowd of lines and bands which occur in the spectrum.

6. The authors underestimate, according to Very, the solar intensity in the infra-red part of the spectrum where terrestrial rays are sent out. For they suppose the energy there is comparable to that of a "black body" at 6,000°, whereas the sun's radiation is much richer in long waves than that of a body at 6,000°. The solar radiation does not correspond to that of a body of uniform temperature, but its infra-red part corresponds to a body at a higher temperature than does its visible part.

7. Mr. Kron is of the opinion that the authors underestimate the solar radiation in the ultra-violet spectrum, owing to the powerful atmospheric absorption there.

8. Mr. Bigelow finds from thermodynamic considerations that our solar-constant values represent the intensity at about 40 kilometers altitude, where the atmospheric pressure is less than $\frac{1}{1000}$ of that at the sea level, but that between this and the limit of the atmosphere the radiation increases from 1.93 to 4 calories.

REPLY TO THESE CRITICISMS.

First objection.—In regard to (1) we may remark, in addition to what we have said above, that nearly all the pyrheliometry now being done in the world is done with Ångström, Marvin, Michelson, or Smithsonian pyrheliometers. These represent five independent attempts to fix the standard scale of radiation. They have been many times compared with each other, and are found in accord to within less than 4 per cent, and now, in view of A. K. Ångström's researches, perhaps to less than 2 per cent. Of these scales of pyrheliometry, ours gives the highest readings. We have devoted much experimenting during many years to the establishment of the standard scale of pyrheliometry. Many observers reduce readings obtained with other pyrheliometers to the Smithsonian scale. Dr. Hellmann has indeed gone so far as to say publicly[7] that there is but one standard pyrheliometer, and that is at the Astrophysical Observatory of the Smithsonian Institution.

Second objection.—In view of the great importance attached by Mr. Very and others to the observation of solar radiation at great air masses, we reexamined some of our observations of former years which were made at larger than the usual air masses. For each of the days we give in the following table ratios of atmospheric transmission coefficients found for different air-mass ranges at many points in the spectrum, first, as obtained by comparing results found at small air masses with those found at large ones, and, second, by comparing those heretofore published with those now obtained at large air masses. For the determination of transmission at large air masses, the observations were replotted, using Bemporad's air-mass tables instead of the secant of the zenith distance. The new plots did not include the observations at small air masses, thus avoiding any prejudice of the observer which might have been caused by seeing them. The results of the comparison appear in the following table. It can not be said that this indicates any considerable fall of transparency as the air mass decreases. Had this been the case the ratios given would in general have been greater than unity. The slight tendency in that direction is hardly beyond the error of determination, and, besides, is to be attributed to the departure of Bemporad's air masses from secant Z values used in our publications heretofore.

[7] Bericht über die Erste Tagung der Strahlungskommission des Internationalen Meteorologischen Komites in Rapperswyl bei Zurich, 2 Sept., 1912.

TABLE 3.—*Ratios of transmission coefficients, small and large air masses.*

Date.	Wave length in microns.	0.384	0.431	0.503	0.598	0.764	1.07	1.45	Mean.	Air-mass range.	
										small m.	large m.
Oct. 2, 1910	Ratio $\frac{\text{small } m}{\text{large } m}$	1.080	1.005	0.993	0.968	1.016	0.975	....	1.006	1.5–2.5	2.5–3.7
	Ratio $\frac{\text{published } m}{\text{large } m}$ ..	1.031	1.014	.995	.983	1.007	.991	....	1.003	....	....
Oct. 6, 1910	.....do..............	.851	.973	1.007	....	1.023	1.021	....	.975	1.4–2.4	2.4–3.6
		.943	.992	1.005	....	1.016	1.019	....	.995		
Oct. 24, 1910	.....do..............	....	1.057	.989	.964	.991	....	....	1.000	1.6–2.6	2.6–3.9
		....	1.036	.998	.988	.995	....	....	1.004		
Nov. 6, 1910	.....do..............	.995	.975	1.023	1.007	1.000	....	0.995	.999	1.7–2.8	2.8–4.0
		.960	.979	1.012	1.000	.997	....	1.002	.992		
Nov. 7, 1910	.....do..............	1.094	1.030	1.038	1.016	....	....	....	1.044	1.7–2.7	2.7–4.2
		1.019	1.040	1.007	1.026	....	....	....	1.023		
Nov. 8, 1910	.....do..............	1.016	1.023	1.012	1.028	.984	....	....	1.013	1.7–2.8	2.8–4.1
		1.000	1.016	1.000	1.010	.993	....	....	1.004		
Nov. 17, 1911	.....do..............	1.109	1.035	1.112	1.026	1.019	1.012	.964	1.039	1.7–2.5	2.5–4.3
		1.034	1.014	1.021	1.014	1.007	1.004	.991	1.012		
Nov. 19, 1911	.....do..............	....	1.002	.982	1.030	1.009	1.014	.984	1.003	1.7–2.6	2.6–4.4
		....	1.007	1.005	1.002	1.007	1.002	1.007	1.005		
Oct. 23, 1913	.....do..............	1.119	.957	1.000	.982	.995	1.014	1.033	1.014	1.5–3.0	3.0–4.5
		1.063	.999	1.007	.986	.993	1.007	1.024	1.011		
Oct. 25, 1913	.....do..............	....	1.007	1.035	.998	1.005	1.005	1.040	1.015	1.5–2.4	2.4–4.6
		....	1.030	1.019	1.007	1.002	1.012	1.038	1.015		
Oct. 26, 1913	.....do..............	.991	1.042	1.042	.989	.995	1.007	....	1.011	1.6–2.4	2.4–4.5
		1.020	1.019	1.012	.989	.998	1.007	....	1.007		
Oct. 28, 1913	.....do..............	1.067	1.016	1.062	1.067	1.038	.984	1.007	1.034	1.6–2.5	2.5–5.0
		1.035	.992	1.002	1.007	1.005	.995	1.007	1.006		
Nov. 4, 1913	.....do..............	.863	1.007	.966	1.002	.982	.980	....	.967	1.6–2.4	2.4–4.7
		.988	1.012	.998	1.008	.997	.998	....	1.000		
Nov. 5, 1913	.....do..............	1.054	.977	.968	1.014	1.002	.991	....	1.001	1.6–2.4	2.4–4.8
		.975	.994	.986	1.007	1.003	.997	....	.994		
Nov. 7, 1913	.....do..............	1.014	1.014	.957	1.002	.993	.984	....	.994	1.7–2.5	2.5–5.0
		1.037	1.014	.980	1.004	.998	.995	.998	1.004		
Nov. 8, 1913	.....do..............	.865	1.067	.982	1.028	1.038	1.012	1.005	1.000	1.7–2.5	2.5–5.2
		.938	1.017	.991	1.009	1.002	1.000	.995	.993		
Means......	.....do..............	**1.009**	**1.012**	**1.010**	**1.008**	**1.006**	**1.000**	**1.004**	**1.007**	....	....
		1.003	**1.011**	**1.002**	**1.003**	**1.001**	**1.002**	**1.008**	**1.004**		

OBSERVATIONS OF SEPTEMBER 20 AND SEPTEMBER 21, 1914.

For a more thorough test we selected two of the driest and clearest days on which we have ever observed on Mount Wilson, namely, September 20 and September 21, 1914, for combined spectrobolometric and pyrheliometric measurements, extending from the moment the sun rose above the horizon [8] until the close of our usual observing period at about 10 o'clock in the forenoon. During this interval we obtained on the first day 11 and on the second day 12 bolographs of the spectrum, extending from wave length 0.34 μ to wave length 2.44 μ, and we made 33 pyrheliometric determinations of the solar radiation on the first day, and 34 such determinations on the second day. We observed the barometric pressure by means of a recording Richard barograph, and we observed the humidity of the air by means of a ventilated Assmann psychrometer.

[8] We computed the apparent zenith distance of the lower limb of the sun at the instant of the start of the first bolograph on Sept. 20 to be 88° 20′. The apparent zenith distance of the mountain horizon at that point is 88° 28′.

The following tables include the barometric, hygrometric, and pyrheliometric data:

TABLE 4.—*Pyrheliometry and meteorological observations, Mount Wilson, California, Sept. 20, 1914.*

Hour angle.	Barometer.	Temperature.		Pressure water vapor.	Air mass (Bemporad).	Pyrheliometer readings.		Precipitable water vapor (Fowle).
		Dry.	Wet.			IV.	VII.	
E h. m.	cm.	°	°	mm.		Calories.[1]	Calories.[1]	mm.
6 06	....	16.5	9.7	6.11	....	....	....	....
5 54.8	61.9	....	....	....	19.31	0.530	....	....
53.8	....	....	....	....	18.32	....	0.558	....
50.8	....	....	....	....	15.82	.620	....	3.3
49.8	....	....	....	....	15.10	....	.636	....
46.8	....	....	....	....	13.89	.676	....	....
45.8	....	....	....	....	13.33	....	.708	....
42.8	....	....	....	....	11.44	.768	....	....
41.8	....	....	....	....	11.03	....	.776	4.0
38.8	....	....	....	....	9.97	.814	....	....
37.8	....	....	....	....	....	....	....	....
34.8	....	....	....	....	8.82	.883	....	....
33.8	....	....	....	....	8.57	....	.900	....
30.8	....	....	....	....	7.91	.922	....	....
29.8	....	....	....	....	7.71	....	.951	....
26.8	....	....	....	....	7.16	.976	....	4.1
25.8	....	....	....	....	7.00	....	.979	....
14.8	....	....	....	....	5.52	1.082	....	4.6
13.8	....	....	....	....	5.42	....	1.093	....
8	....	16.7	9.4	5.71	5.05	....	....	....
4.8	....	....	....	....	4.67	1.146	....	....
3.8	....	....	....	....	4.59	....	1.143	4.9
4 48.8	....	....	....	....	3.74	1.232	....	....
47.8	....	....	....	....	3.69	....	1.229	....
44.8	....	....	....	....	3.56	1.242	....	5.2
43.8	....	....	....	....	3.52	....	1.262	....
39	....	17.4	8.6	4.62	3.35	....	....	....
32.8	....	....	....	....	3.11	1.292	....	....
31.8	....	....	....	....	3.08	....	1.291	5.9
9.8	....	....	....	....	2.53	1.371	....	....
8.8	62.0	....	....	....	2.51	....	1.407	5.0
3 44	....	18.2	12.2	8.06	2.108	....	....	....
38.8	....	....	....	....	2.044	1.435	....	....
37.8	....	....	....	....	2.032	....	1.439	5.8
2 50.8	....	....	....	....	1.615	1.496	....	....
49.8	....	....	....	....	1.609	....	1.497	6.6
44	....	20.2	14.1	9.41	1.573	....	....	....
2.8	....	....	....	....	1.383	1.516	....	....
1.8	....	....	....	....	1.380	....	1.516	8.6
1 56	62.0	21.4	15.0	9.99	1.360	....	....	....

[1] See note 1, Table 9.

TABLE 5.—*Pyrheliometry and meteorological observations, Mount Wilson, California, Sept. 21, 1914.*

Hour angle.	Barometer.	Temperature.		Pressure water vapor.	Air mass (Bemporad).	Pyrheliometer readings.		Precipitable water vapor (Fowle).
		Dry.	Wet.			IV.	VII.	
E *h. m.*	*cm.*	°	°	*mm.*		*Calories.*[1]	*Calories.*[1]	*mm.*
6 00		15.4	5.1	2.21				
5 54.8	62.1				20.36	0.489		
53.8					19.34		0.523	
50.8					16.62	.578		3.8
49.8					15.85		.616	
46.8					13.89	.655		
45.8					13.33		.689	
42.8					11.86	.719		
41.8					11.42		.755	4.9
38.8					10.31	.788		
37.8					9.98		.798	
34.8					9.10	.844		
33.8					8.84		.857	
30.8					8.12	.880		6.1
29.8					7.91		.903	
26.8					7.33	.914		
25.8					7.16		.944	
20		17.2	8.0	4.12				6.5
15.8					5.76	1.027		
14.8					5.66		1.049	
11.8					5.34	1.061		
10.8					5.25		1.086	7.1
4 58.8					4.32	1.148		
57.8					4.25		1.163	
52		17.1	6.2	2.48	4.00			7.2
41.8					3.46	1.248		
40.8					3.42		1.250	7.4
26.8					2.97	1.297		
25.8					2.94		1.312	7.5
15		17.7	7.1	3.06	2.67			
5.8					2.47	1.366		
4.8	62.15				2.45		1.370	8.0
3 42		18.4	10.3	5.92	2.097			
35.8					2.022	1.419		
34.8					2.010		1.438	8.2
2 51		20.3	10.9	5.74	1.625			
47.8					1.606	1.492		
46.8					1.600		1.498	8.7
2 00	6.22	22.2	13.2	7.49	1.381			
1 49.8					1.348	1.529		
48.8					1.345		1.533	8.3

[1] See note 1, Table 9.

The two days, September 20 and September 21, are in almost complete agreement in every feature observed, except that the atmospheric humidity of September 21 slightly exceeded that of September 20, and this, of course, led to a slight difference in pyrheliometry. We give below our reduction of the spectrobolometric work of September 20, and the circumstances of the observations will be found so completely set forth that if any readers should desire, they can re-reduce the day's work for themselves.

It is the principal aim of the investigation to determine if there was on these two days a systematic change of atmospheric transparency sufficient to vitiate solar constant values obtained by our usual method. Referring to our Annals, Volume II, page 14, it may be shown that for solar zenith distances less than 70° the intensities of homogeneous rays observed at different zenith distances should be expressible by the relation:

$$\log e = \text{secant } z \log a + \log e_0$$

where e is the observed intensity of a homogeneous ray; e_0 its intensity outside the atmosphere; z the zenith distance of the sun; a a constant representing the fraction $\frac{e_1}{e_0}$ in which e_1 is the intensity which would correspond to $z=0$. The above equation being the equation of a straight line, the test of the uniformity of transparency depends on the closeness with which the logarithmic plots for individual wave lengths approximate straight lines.

For zenith distances much greater than 70° the function secant z must be replaced by another, $F(z)$, representing the ratio of the effective length of path of the beam in the atmosphere to that which corresponds to $z=0$. This quantity, $F(z)$, has been determined by Bemporad,[9] taking into account the curvature of

[9] Mitteilungen der Grossh. Sternwarte zu Heidelberg IV, 1904. The following illustrates a computation of air mass $F(z)$.

EXAMPLE OF AIR-MASS COMPUTATION.

For mean 120° meridian time:	
1914, Sept. 20, $5^h\ 51^m\ 0^s$ (i. e., $1^m\ 50^s$ after start of first bolograph).	
Barometer 24.4 inches=620 mm, temperature=60° F.=16° C.	
Longitude 118° 3′ 34″ W., equation of time	$+\ 6^m\ 22^s$
Latitude, ϕ, 34° 12′ 55″ N., correction for longitude	$+\ 7^m\ 46^s$
	$+14^m\ 8^s$
⊙ Declination, δ, 1° 17′ 28″ N., apparent time	$6^h\ 5^m\ 8^s$
Hour angle, t, 88° 43′ 0″ E., hour angle	$5^h\ 54^m\ 52^s$
Sun's true altitude h:	
$\sin h = \sin \phi \sin \delta + \cos \phi \cos \delta \cos t$	$h=$ 1° 47′ 14″
Sun's true zenith distance	88° 12′ 46″
By Crawford's tables (Lick Observatory Publications, Vol. VII):	
If apparent zenith distance is 87° 50′	Refr.=13′ 46″
If apparent zenith distance is 87° 58′	Refr.=14′ 14″
Hence assume	Refr.=14′ 16″
Whence sun's apparent zenith distance is	87° 58′ 30″
By Bemporad's air-mass tables:	
If apparent zenith distance is 87° 58′ 30″	$F(z)=$ 19.650
But if $B=620$, $T=16°$	$F^1(z)-F(z)=-0.433$
Hence air mass, $F^1(z)$	$=$ 19.216

the earth, the atmospheric refraction, and the fall of temperature and barometer with elevation. His assumption regarding the rate of fall of temperature is not quite in accord with recent balloon work, and this leads him to values of $F(z)$ slightly too high, but this error would not exceed 0.5 per cent. As is well known, the atmospheric refraction is uncertain very near the horizon, so that it can not be expected that the air masses obtained with apparent zenith distances of 88°, computed from hour angles of observation, should be perfectly accurate.

Strictly, we should determine the value, $F(z)$, to correspond to the apparent center of intensity of the sun's light emission at the proper instant for every wave length, for on account of atmospheric extinction and refraction this is not coincident with the center of form of the sun. But we have found the correction to be always less than 0.5 per cent, and have neglected it.

A far more important consideration relates to the distribution in the atmosphere of the materials which diminish the intensity of sunlight, as the zenith distance increases. Bemporad's discussion assumes that the atmosphere is of uniform optical quality from top to bottom, so that equal masses of it transmit equal fractions of incident light. The researches of Schuster, Natanson, King, Fowle, and Kron show that on clear days at Mount Wilson the atmospheric extinction, for a large part of the spectrum, seems to be in almost complete accord with the requirements of Rayleigh's theory of scattering. Where this holds, Bemporad's assumption also holds good. But it appears distinctly from Fowle's researches that in certain parts of the spectrum, notably in the yellow, red, and infra-red, the atmospheric extinction is partly or mainly attributable to water vapor, or substances which accompany it. These atmospheric constituents, being mainly at low altitudes, require special consideration. We give in the following paragraphs our solution of this difficulty.

Fowle has determined transmission coefficients similar in their application to the values a given above, but dependent on the total quantity of precipitable water in the atmosphere as determined spectroscopically. He gives the following values of the transmission coefficients for dry air ($a_{a\lambda}$) and for the equal of 1 cm of liquid as water vapor ($a_{w\lambda}$) above Mount Wilson. We employ values obtained from observations of 1910 and 1911, in preference to later ones, because obtained prior to the volcanic eruption of 1912.

Table 6.—*Coefficients of transmission for the dry atmosphere and for atmospheric water vapor (Fowle).*

Wave length λ	0.350	0.360	0.371	0.384	0.397	0.413	0.431	0.452	0.475	0.503	0.535	0.574	0.598	0.624
$a_{a\lambda}$	.632	.655	.686	.713	.752	.783	.808	.840	.863	.885	.898	.905	.913	.929
$a_{w\lambda}$	.917	.940	.959	.959	.962	.965	.968	.967	.973	.976	.980	.974	.978	.977

Wave length λ	0.653	0.686	0.722	0.764	0.812	0.864	0.987	1.146	1.302	1.452	1.603
$a_{a\lambda}$	.938	.959	.970	.979	.980	.982	.987	.987	.986	.989	.983
$a_{w\lambda}$	.987	.985	.989	.985	.990	.989	.991	.988	.990	.988	.986

These water-vapor coefficients apply to smoothed energy curves, and are a measure of the general extinction associated with water vapor apart from its selective absorption.

By Rayleigh's theory the dry-air coefficients may be calculated from the known number of molecules of air per cm^3 at standard temperature and pressure. This computation is in close accord with the values above given. We hold therefore that Rayleigh's theory of scattering would yield proper values of general atmospheric extinction, for clear days on Mount Wilson, if water vapor were absent. As our observed general transmission coefficients in the infra-red spectrum are somewhat less accurate than elsewhere, owing to the necessity of interpolating the curves over the water vapor bands, and from other causes, we have thought it right to compute by Rayleigh's theory the true transmission coefficients in this region as they would be if molecular scattering alone were the active agent.

Table 7.—*Computed atmospheric transmission and extinction coefficients.*

Wave length	0.764	0.812	0.864	0.922	0.987	1.062	1.146	1.226	1.302	1.377
Computed $a_{a\lambda}$	.979	.9838	.9873	.9903	.9925	.9954	.9959	.9969	.9975	.9980
$1-a_{a\lambda}$	.021	.0162	.0127	.0097	.0075	.0046	.0041	.0031	.0025	.0020
$1-a_{\frac{w}{2}\lambda}$	.007	.005	.005	.005	.005	.005	.005	.005	.005	.010

As appears above, the computed transmission for wave lengths exceeding 1.37μ is approximately unity, and the computed atmospheric extinction coefficient, as given in line 3, sensibly zero. Line 4 gives the general extinction for 0.5 centimeter of precipitable water vapor, corresponding to the humidity of September 20, 1914.

We are now in position to determine a correction to $F(z)$ as given by Bemporad. If the extinction were all molecular scattering, his values would be the true ones. If it were all due to water vapor, we ought to employ approximately secant z, because of the low level of water vapor. We have therefore determined for each wave length the weighted mean between Bemporad's $F(z)$ and secant z, giving weights in proportion to the numbers $(1-a_{a\lambda})$ and $(1-a_{\frac{w}{2}\lambda})$ for wave lengths less than 0.764μ, and in proportion to the numbers $(1-a_{c\lambda})$ and $(1-a_{\frac{w}{2}\lambda})$ for wave lengths exceeding 0.764μ. In one case we have made an exception, namely, for wave length 2.348μ, which is within the band of carbon-dioxide absorption. As this gas forms a nearly constant percentage of the atmosphere up to a level of more than 10,000 meters, we have used Bemporad's $F(z)$ at this wave length. In figures 50 and 51 the reader will see the plotted air masses as used, and also the lesser air masses corresponding to Bemporad's $F(z)$.

The following are the circumstances of the spectrobolometric observations of September 20, 1914:

Extent of spectrum observed (in arc) 270′. Bolometer subtends 17″. Slit subtends 50″.
Extent of spectrum observed in wave lengths: $\lambda=0.342\ \mu$ to $\lambda=2.348\ \mu$.
Time elapsing after start $0^m\ 30^s$ to $7^m\ 15^s$.

Bolograph No.	1	2	3	4	5	6	7	8	10[1]	11
	h. m. s.	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*	*h. m.*
Time of start; 120th meridian mean time..	5 49 10	5 59	6 12	6 25	6 40	6 55	7 11	7 33	8 52	9 40
Latitude, 34° 12′ 55″ N. Longitude, 118° 3′ 34″ W. Altitude, 1,727 meters.										

[1] Bolograph 9 omitted because of interference of a guy wire.

In accordance with our usual course, described in Volume III of our Annals, we measured the ordinates of smoothed curves on all the bolographs at 38 wave lengths. These were equally spaced in prismatic deviation, excepting that in a portion of the infra-red spectrum we observed at points twice as close together as in the other parts of the spectrum. Table 8 includes the measured ordinates of the smoothed curves (unit 0.1 mm) and corresponding air masses, according to Bemporad, for September 20. Our corrected air masses appear only on figures 51 and 52. The third column of the table gives the factor to reduce the uniform scale throughout the spectrum.

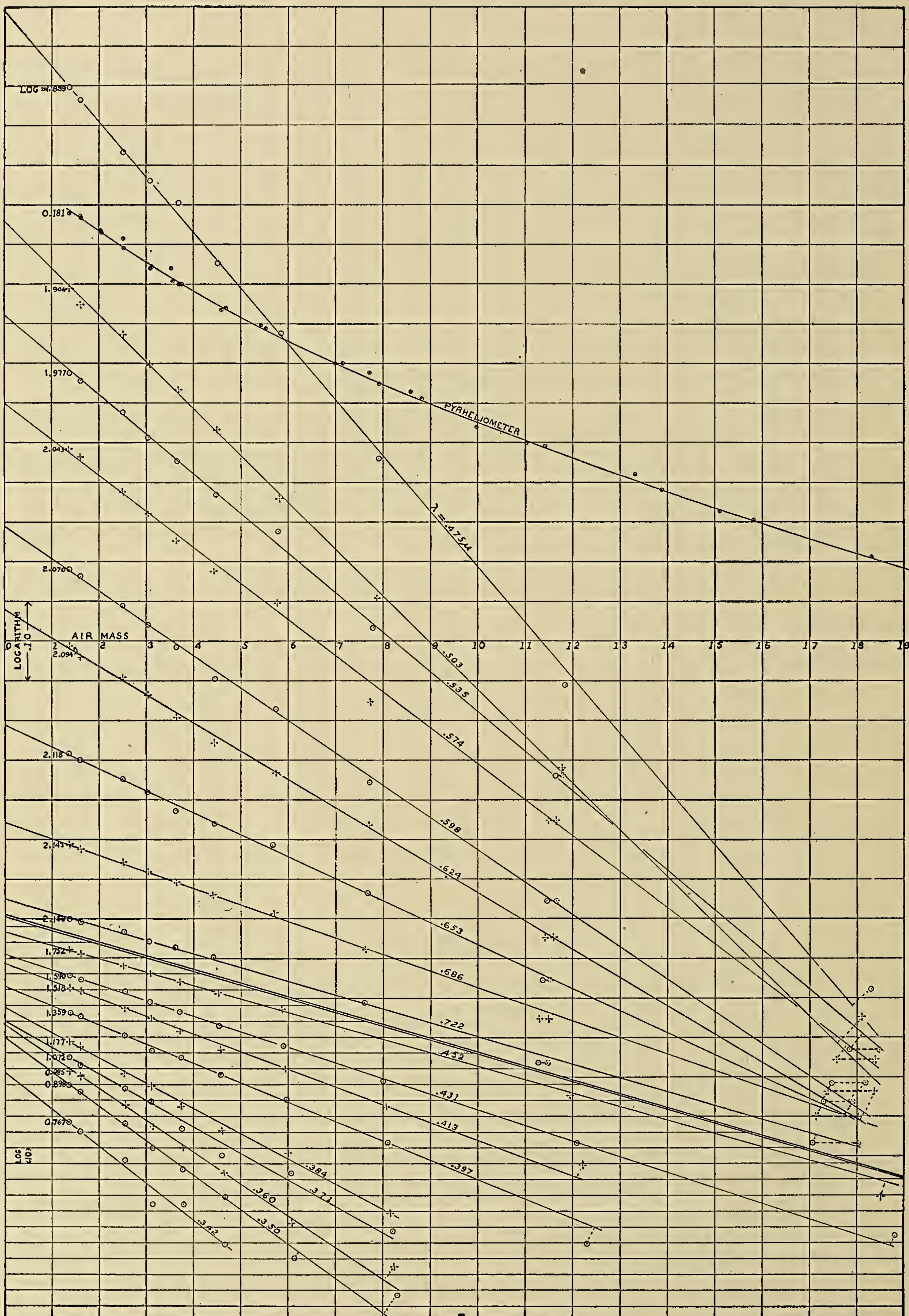

FIG. 51.—Logarithmic curves of atmospheric transmission. Mount Wilson, Sept. 20, 1914. Note the two scales of ordinates.

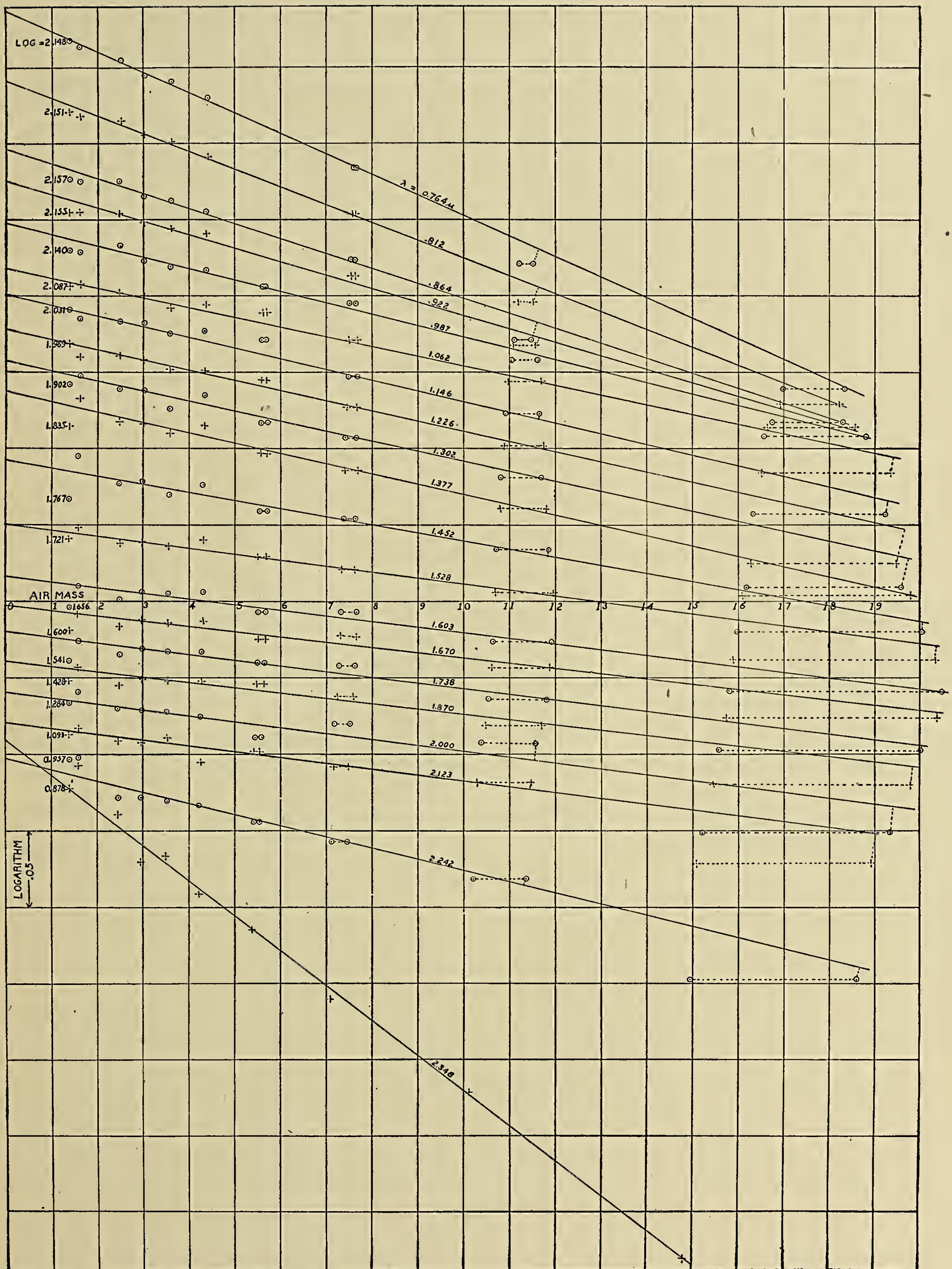

Fig. 52.—Logarithmic curves of atmospheric transmission, Mount Wilson, Sept. 20, 1914.

TABLE 8.—*Air masses and smoothed curve ordinates—Bolographs of Sept. 20, 1914.*

Prismatic deviation from ω_1.	Wave length.	Correcting factor[1] for transmission through optical apparatus.	Bolograph I.		Bolograph II.		Bolograph III.[3]		Bolograph IV.		Bolograph V.		Bolograph VI.		Bolograph VII.		Bolograph VIII.		Bolograph X.[4]		Bolograph XI.	
			Galvanometer deflection.[2]	Air mass (Bemporad).	Deflection.[2]	Air mass (Bemporad).	Deflection.[2]	Air mass (Bemporad).	Deflection.[2]	Air mass (Bemporad).	Deflection.[2]	Air mass (Bemporad).	Deflection.[2]	Air mass (Bemporad).	Deflection.[2]	Air mass (Bemporad).	Deflection.[2]	Air mass.	Deflection.[2]	Air mass.	Deflection.[2]	Air mass.
′	μ																					
240	0.342	0.352	(5)	......	(5)	......	(5)	......	(5)	......	28	4.68	50	3.80	50	3.15	100	2.57	150	1.63	165	1.39
230	.350	.215	......	......	......	......	17	8.31	?30	6.14	72	4.67	108	3.79	148	3.14	212	2.56	340	1.63	365	1.39
220	.360	.139	......	......	......	......	41	8.26	?77	6.10	158	4.65	228	3.78	315	3.14	440	2.56	660	1.63	690	1.39
210	.371	.317	......	......	......	......	30	8.21	?70	6.07	90	4.63	132	3.77	196	3.13	240	2.55	345	1.63	370	1.39
200	.384	.270	......	......	......	......	46	8.16	111	6.02	152	4.61	217	3.75	290	3.12	356	2.55	530	1.62	553	1.39
190	.397	.264	......	......	30	12.3	131	8.12	244	5.99	350	4.59	453	3.74	500	3.11	630	2.55	840	1.62	860	1.39
180	.413	.630	......	......	40	12.2	92	8.07	160	5.96	210	4.58	280	3.73	338	3.10	390	2.54	510	1.62	520	1.38
170	.431	.584	?15	18.8	59	12.1	143	8.01	240	5.93	323	4.55	393	3.72	456	3.10	545	2.54	642	1.62	663	1.38
160	.452	.544	?36	18.5	126	12.0	94	7.95	440	5.89	562	4.53	650	3.70	740	3.09	845	2.53	1,012	1.62	1,033	1.38
150	.475	1.53	?33	18.3	79	11.9	153	7.91	220	5.86	268	4.52	320	3.69	345	3.08	380	2.53	443	1.62	447	1.38
140	.503	1.43	68	18.1	140	11.8	228	7.87	305	5.82	369	4.50	417	3.68	452	3.07	499	2.52	548	1.61	558	1.38
130	.535	1.33	100	17.9	223	11.6	340	7.80	430	5.80	497	4.48	550	3.67	595	3.06	648	2.52	716	1.61	709	1.38
120	.574	1.24	151	17.6	304	11.5	427	7.75	568	5.77	618	4.46	680	3.66	740	3.06	798	2.51	890	1.61	884	1.38
115	.598	1.20	220	17.5	377	11.5	528	7.73	650	5.75	708	4.45	780	3.65	838	3.05	897	2.51	983	1.61	973	1.38
110	.624	1.16	293	17.4	460	11.4	637	7.71	738	5.74	804	4.44	870	3.65	930	3.05	992	2.51	1,062	1.61	1,063	1.38
105	.653	1.12	425	17.3	608	11.4	780	7.69	896	5.73	950	4.44	990	3.64	1,055	3.05	1,110	2.51	1,178	1.61	1,164	1.38
100	.686	1.09	580	17.2	773	11.3	942	7.64	1,045	5.71	1,096	4.42	1,143	3.64	1,187	3.04	1,238	2.50	1,293	1.61	1,266	1.38
95	.722	1.07	687	17.1	872	11.3	1,033	7.63	......	5.69	1,176	4.42	1,210	3.63	1,245	3.04	1,296	2.50	1,336	1.61	1,312	1.38
90	.764	1.06	783	17.0	950	11.2	1,093	7.61	......	5.69	1,208	4.41	1,244	3.62	1,265	3.03	1,310	2.50	1,345	1.60	1,317	1.38
85	.812	1.10	826	16.9	959	11.2	1,102	7.59	......	5.68	1,192	4.40	1,225	3.62	1,250	3.03	1,294	2.49	1,308	1.60	1,277	1.38
80	.864	1.17	850	16.8	966	11.1	1,086	7.56	......	5.66	1,158	4.39	1,183	3.61	1,200	3.03	1,243	2.49	1,250	1.60	1,220	1.38
75	.922	1.24	834	16.7	948	11.1	1,046	7.54	......	5.65	1,108	4.38	1,120	3.60	1,138	3.02	1,170	2.49	1,180	1.60	1,144	1.38
70	.987	1.29	807	16.6	912	11.0	987	7.52	1,010	5.63	1,030	4.37	1,040	3.60	1,057	3.02	1,098	2.49	1,092	1.60	1,063	1.38
65	1.062	1.28	719	16.5	830	11.0	878	7.50	913	5.62	920	4.37	920	3.60	943	3.02	960	2.48	978	1.60	947	1.38
60	1.146	1.26	626	16.4	732	10.9	770	7.47	813	5.60	819	4.36	820	3.59	840	3.01	852	2.48	860	1.60	846	1.38
55	1.226	1.23	543	16.3	652	10.9	688	7.45	714	5.59	722	4.35	727	3.58	742	3.01	758	2.48	759	1.60	752	1.37
50	1.302	1.20	489	16.2	580	10.8	613	7.43	626	5.58	650	4.34	640	3.58	662	3.00	673	2.48	690	1.60	660	1.37
45	1.377	1.17	452	16.1	519	10.8	546	7.41	560	5.57	580	4.34	577	3.58	589	3.00	600	2.47	623	1.60	580	1.37
40	1.452	1.14	420	16.0	478	10.7	498	7.37	503	5.55	520	4.32	516	3.57	528	3.00	535	2.47	560	1.60	510	1.37
35	1.528	1.12	392	15.9	436	10.7	448	7.35	455	5.53	465	4.31	463	3.56	470	2.99	475	2.47	488	1.60	466	1.37
30	1.603	.363	1,100	15.8	1,190	10.7	1,240	7.33	1,237	5.52	1,268	4.31	1,270	3.56	1,280	2.99	1,286	2.47	1,311	1.60	1,240	1.37
25	1.670	.356	982	15.7	1,065	10.6	1,111	7.31	1,103	5.52	1,130	4.30	1,132	3.56	1,144	2.99	1,150	2.46	1,178	1.60	1,110	1.37
20	1.738	.353	862	15.6	935	10.6	977	7.28	980	5.50	992	4.29	998	3.55	1,008	2.98	1,011	2.46	1,038	1.59	978	1.37
10	1.870	.370	620	15.5	682	10.5	708	7.25	718	5.47	720	4.28	722	3.54	730	2.97	733	2.45	758	1.59	720	1.37
0	2.000	.422	375	15.2	432	10.4	440	7.19	452	5.44	442	4.26	447	3.53	453	2.97	460	2.45	474	1.59	453	1.37
−10	2.123	.176	580	15.1	660	10.3	670	7.16	695	5.42	670	4.24	700	3.52	700	2.96	710	2.45	730	1.59	700	1.37
−20	2.242	.239	272	15.0	318	10.2	335	7.12	350	5.40	350	4.23	355	3.51	360	2.96	365	2.45	390	1.59	375	1.37
−30	2.348	.307	120	14.8	155	10.1	180	7.07	210	5.38	210	4.21	220	3.50	220	2.95	240	2.44	260	1.59	245	1.37

1 This factor includes consideration of rotating sectors used, reflecting power of coelostat, and transmission in spectroscope.
2 Galvanometer deflections are here expressed in tenths of millimeters.
3 Bolograph III is a little low in a few points by interference of leaves of a tree.
4 Bolograph IX is omitted because a guy wire interfered.
5 Extremely doubtful points, and those for which deflections are less than 1 millimeter, are omitted.

After reducing the measured ordinates (by means of factors given) for transmission in the apparatus, in accordance with the practice of Langley and ourselves, we corrected these new ordinates of the bolographs for the slight changes of sensitiveness of the bolometric apparatus. We determined these changes of sensitiveness by comparing the areas included under the bolographic curves with the readings of the pyrheliometer simultaneously obtained. The determination of these secondary correcting factors and of the mean bolometer constant for September 20 follows:

TABLE 9.—*Sensitiveness of bolographic apparatus.*

Bolograph.	Hour angle.	Air mass.	Smooth curve area of bolograph.	Correction for ultra-violet.	Correction for infra-red.	Correction for water vapor and oxygen bands.	Corrected area.	Corresponding pyrheliometry, calories.	Factor to reduce corrected areas to calories.	Correcting factor in percentage.	Correcting logarithm.
	h m										
I......	5 53.5	17.15	7475	....	+109	−2135	5449	0.583	1.070	+7.3	[1]0.031
II.....	42.7	11.39	9630	....	127	2094	7663	.764	0.997	±0.0	.000
III....	29.8	7.71	11129	....	132	2000	9261	.943	....	....	[2]
IV....	16.9	5.75	12436	....	138	1961	10613	1.066	1.004	+0.7	.003
V.....	2.0	4.46	13232	+ 1	136	1887	11482	1.159	1.009	+1.2	.005
VI....	4 47.3	3.67	13930	25	140	1819	12276	1.233	1.003	+0.6	.003
VII...	31.3	3.06	14622	41	140	1807	12996	1.294	0.996	−0.1	.000
VIII..	10.0	2.53	15474	79	144	1692	14005	1.377	0.983	−1.4	.994
X[3]....	2 51.0	1.62	16576	163	150	1624	15265	1.495	0.979	−1.8	[3] .992
XI....	3.0	1.38	16317	179	144	1609	15031	1.515	1.008	+1.1	.005
Mean..	....	....	....	....	....	....	....	....	0.997		

[1] The correcting factor for bolograph I is much above the usual magnitude. It was not used for the following reasons: Firstly, the pyrheliometer exposes $\frac{1}{350}$ hemisphere, which is a sky area much larger than the sun. At ordinary air masses the light of this area of sky is negligible compared with sunlight. But at sunrise almost two-thirds of the solar beam is lost by scattering in the sky, hence the light of the sky close to the sun is a very perceptible fraction, perhaps 5 per cent, of that of the sun itself. Secondly, the radiation of the pyrheliometer to cold air and to space, which at high sun may reach nearly 0.005 calorie, is at the horizon counterbalanced by the radiation of the immense thickness of the lower and warmer parts of the atmosphere, so that in comparison with high sun observations the pyrheliometer reading at sunrise is probably about 1 per cent too high for this second cause. Exact determinations of these corrections to pyrheliometry are proposed, but not yet executed. Accordingly bolograph I was omitted in the mean of column 10.

[2] Correction could not be determined because leaves of a tree intercepted the solar beam during a part of bolograph III.

[3] Bolograph IX omitted, because shadow of a guy wire fell on the slit during a considerable part of the time.

In figures 51 and 52 we give plots to represent the results of the spectrobolometric observations of September 20 at different wave lengths. The plots given in figures 51 and 52 are logarithmic. The ordinates correspond to logarithms of the corrected heights of the bolographs at the 38 selected points, and the abscissæ of the diagrams represent the corresponding air masses according to the tables of Bemporad, corrected as heretofore explained.

The original plots have been made on two different scales. In the first, only those observations which we would ordinarily have used for determining the solar constant of radiation were included. They were plotted on the scales of ordinates and abscissæ which we customarily employ, in which, in general, 1 cm=0.01 in logarithm, and 1 cm=0.1 air mass. In the other plot we have included all the observations, using for this purpose a reduced scale of abscissæ, in which 1 cm=0.5 air mass.

We have read off from the plots so obtained the inclination of the best straight lines, giving logarithms of transmission coefficients; and also the intercepts on the axis of ordinates, giving logarithms of intensities outside the atmosphere. The plots were read up independently for three different ranges of air masses. The first range is that which we customarily employ, from about 1.3 to about 4.5 air masses. The second reading includes all points from 1.3 to 20 air masses or thereabouts. The third reading was made with the portion of the curve which Mr. Very states to be the best, namely, from air mass 4 to air mass 10 or thereabouts. The results of all three readings are given in Table 11. For September 20 this table gives also the percentage deviations, in ordinates, of the observed points from the natural numbers corresponding to the straight lines of the logarithmic plots which were chosen in the second reading to represent them. In order to show that the somewhat large percentage errors at some places are not inconsistent with experimental error of very moderate amount, we give for two bolographs the deviations expressed in millimeters on the original bolographs. The reader should bear in mind that the bolographic trace itself is nearly 1 millimeter wide, and subject to tremor. Also the line of zero radiation is interpolated between zero marks 1 minute of time, or 8 centimeters of plate, apart.

We then determined the area which the bolographic curve would include if it were taken outside the atmosphere, and we multiplied this area by the appropriate constant (see Table 9) to give the result in calories per square centimeter per minute. To this we added the small corrections to reduce the result to mean solar distance, and to zero atmospheric humidity, as explained in Annals, Volume III, page 43. All the details of the foregoing processes have been described and investigated in Volumes II and III of the Annals of the Astrophysical Observatory, and to these the reader is referred.

The following are the solar-constant values obtained:

Table 10.—*Solar-constant values.*

[In standard calories (15°) per cm² per minute at mean solar distance.]

Air masses	1.3 to 4	1.3 to 20	4 to 12
Sept. 20	1.936	1.899	1.909
Sept. 21	1.960	1.955	1.929

We call attention to the decided difference between the behavior of nearly homogeneous rays, as observed by the bolometer, and of the total radiation, as observed by the pyrheliometer. The logarithms of the pyrheliometer readings of September 20 are plotted against Bemporad air masses in the upper curve of figure 51, and the reader will readily perceive the pronounced and steady change of curvature of the resulting plots. This is in sharp distinction to the close approximation to straight lines shown in the logarithmic plots of the bolometric observations at single wave lengths. Forbes, Radau, Langley, and many others have discussed this relation between total radiation and air masses, and have shown why such a curvature must occur in logarithmic plots of total radiation. It will be seen that our observations fully confirm their view, which depends upon the fact that the total radiation is composed of parts for which the atmosphere has very different transmission coefficients.

TABLE 11.—*Atmospheric transmission coefficients and accidental errors.*

Wave length.	Atmospheric transmission coefficients.						Percentage deviations, Sept. 20, computed minus observed, for observed intensities found on bolograph numbers.										Linear deviations on original bolographs in millimeters.	
	Sept. 21, 1914, air masses.			Sept. 20, 1914, air masses.														
	1.3 to 4	1.3 to 20	4 to 12	1.3 to 4	1.3 to 20	4 to 12	I	II	III	IV	V	VI	VII	VIII	X	XI	I	VII
μ																		
0.342	0.621	0.600	0.637	0.615	0.585	......	......	......	......	......	0.0	+10.4	−27.9	+10.4	0.0	0.0	......	1.1
.350	.621	.575	.575	.600	.600	0.637	......	......	+51.4	−14.8	+ 2.3	− 2.3	− 3.5	+ 2.3	+ 1.6	− 0.5	......	0.5
.360	.643	.625	.658	.618	.667	.652	......	......	+34.9	− 7.2	0.0	− 3.5	− 2.8	+ 2.3	+ 1.6	− 1.2	......	0.8
.371	.661	.678	.682	.681	.679	.718	......	......	+11.7	+13.5	−20.2	−12.2	+ 2.3	0.0	− 2.3	0.0	......	0.5
.384	.681	.692	.697	.631	.692	.702	......	......	+ 1.2	+10.2	+10.2	− 7.2	0.0	− 2.3	+ 2.3	+ 1.2	......	0.0
.397	.745	.731	.728	.743	.753	.753	......	−28.8	0.0	+ 3.5	0.0	+ 1.2	− 6.7	0.0	+ 1.2	0.0	......	3.3
.413	.769	.766	.766	.764	.773	.783	......	+23.0	− 1.2	− 1.2	− 8.4	− 2.3	0.0	0.0	+ 1.2	0.0	......	0.0
.431	.778	.794	.802	.794	.798	.796	−18.9	0.0	− 3.5	0.0	− 1.2	0.0	0.0	+ 4.7	0.0	0.0	0.2	0.0
.452	.841	.824	.824	.820	.820	.832	−25.9	− 4.7	− 2.3	+ 2.3	0.0	− 0.7	0.0	0.0	0.0	+ 2.3	0.7	0.0
.475	.843	.836	.836	.859	.851	.830	+12.7	− 5.0	2.6	+ 0.2	− 0.9	+ 3.3	0.0	− 0.7	0.0	0.0	0.5	0.0
.503	.879	.867	.867	.881	.873	.875	+ 5.2	+ 1.4	− 2.6	− 1.6	+ 0.5	+ 0.9	+ 0.2	+ 1.4	− 1.9	− 0.7	0.3	0.1
.535	.891	.891	.891	.893	.892	.895	− 0.5	0.0	− 1.4	+ 4.0	− 0.7	− 0.5	− 0.5	+ 0.7	− 0.5	− 0.9	0.0	0.3
.574	.897	.900	.900	.889	.903	.904	0.0	0.0	− 6.2	+ 2.3	− 2.1	− 1.2	0.0	+ 0.9	+ 1.9	+ 1.6	0.0	0.0
.598	.900	.906	.908	.904	.911	.908	+ 8.1	0.0	− 2.3	+ 0.7	− 2.3	− 0.9	0.0	+ 0.7	+ 0.9	+ 0.7	1.7	0.0
.624	.900	.918	.925	.916	.921	.920	+11.2	0.0	+ 0.7	− 0.2	− 2.1	− 1.4	0.0	+ 0.9	− 0.5	+ 0.7	3.7	0.0
.653	.931	.942	.942	.933	.936	.938	+ 1.2	− 0.5	0.0	+ 1.2	− 0.5	− 1.9	− 0.2	0.0	0.0	+ 0.5	0.5	0.2
.686	.948	.954	.953	.953	.953	.954	+ 1.2	− 1.9	0.0	+ 0.9	0.0	0.0	+ 0.2	+ 0.2	0.0	0.0	0.7	0.2
.722	.959	.961	.960	.966	.961	.960	+ 1.2	− 1.9	0.0	+ 0.7	+ 0.2	0.0	+ 0.5	− 0.2	− 0.2	− 0.2	0.8	0.6
.764	.966	.970	.971	.973	.970	.968	− 0.2	− 2.6	− 0.2	......	+ 0.5	+ 0.5	− 0.2	+ 0.5	− 0.5	− 0.2	0.2	0.3
.812	.968	.977	.979	.980	.974	.972	0.0	− 2.6	+ 0.5	......	+ 0.5	+ 0.5	0.0	+ 0.7	− 0.9	− 0.9	0.0	0.0
.864	.968	.982	.984	.982	.978	.973	0.0	− 2.8	+ 0.7	......	+ 0.7	+ 0.5	0.0	+ 0.9	− 0.9	− 0.9	0.0	0.0
.922	.975	.985	.987	.982	.980	.978	+ 0.5	− 1.2	+ 1.2	......	+ 0.9	+ 0.2	− 0.2	0.0	+ 1.4	− 1.9	0.4	0.2
.987	.984	.990	.992	.986	.983	.982	0.0	− 0.7	+ 0.9	0.0	+ 0.5	− 0.5	− 0.5	+ 0.9	− 1.4	− 1.6	0.0	0.5
1.062	.984	.990	.992	.984	.985	.984	− 2.3	0.0	+ 0.5	+ 1.9	+ 0.9	− 0.7	+ 0.5	0.0	0.0	− 0.5	1.6	0.5
1.146	.989	.990	.993	.986	.984	.983	− 2.1	+ 0.9	0.0	+ 2.3	+ 1.4	0.0	+ 0.5	0.0	− 0.9	0.0	1.3	0.4
1.226	.984	.988	.990	.989	.985	.983	− 5.7	+ 0.5	0.0	+ 1.2	+ 0.5	− 0.5	0.0	0.0	− 1.6	0.0	3.1	0.0
1.302	.980	.987	.988	.984	.985	.984	− 4.7	0.0	0.0	− 0.7	+ 1.4	− 1.6	0.0	− 0.5	+ 0.2	− 1.4	2.3	0.0
1.377	.986	.990	.990	.980	.985	.983	0.0	+ 0.7	0.0	− 0.5	+ 1.6	− 0.7	− 0.2	− 0.7	+ 1.4	− 3.0	0.0	0.1
1.452	.986	.991	.991	.977	.988	.988	− 1.4	+ 0.9	+ 0.5	− 0.7	+ 1.4	− 0.7	+ 0.5	− 0.5	+ 2.3	− 4.2	0.6	0.2
1.528	.989	.993	.992	.991	.991	.990	− 2.1	+ 0.5	0.0	+ 0.2	+ 1.6	0.0	0.0	− 0.5	+ 0.9	− 0.9	0.8	0.0
1.603	.986	.994	.994	.995	.992	.991	0.0	+ 0.2	+ 1.2	− 0.5	+ 1.4	+ 0.5	0.0	− 1.4	0.0	− 3.5	0.0	0.0
1.670	.986	.994	.994	.998	.992	.992	− 0.7	0.0	+ 1.4	− 0.7	+ 0.9	+ 0.2	+ 0.2	− 0.9	0.0	− 2.8	0.7	0.2
1.738	.989	.991	.994	.995	.992	.991	− 0.7	0.0	+ 1.4	+ 0.2	+ 0.7	0.0	0.0	− 1.2	0.0	− 3.3	0.6	0.0
1.870	.984	.991	.995	.991	.992	.990	− 2.8	− 0.2	+ 0.7	+ 0.9	+ 0.5	0.0	− 0.2	− 1.6	+ 0.5	− 1.9	1.7	0.2
2.000	.973	.992	.995	.991	.991	.994	− 3.8	+ 2.6	+ 2.6	− 1.9	+ 0.2	+ 0.2	0.0	− 0.2	+ 1.6	− 0.5	1.6	0.0
2.123	.991	.991	.992	.989	.991	.992	− 4.7	+ 1.2	0.0	+ 0.5	− 2.1	+ 0.9	− 0.2	− 0.5	+ 0.5	− 0.5	2.7	0.1
2.242	.980	.979	.986	.966	.983	.983	− 1.9	+ 1.2	0.0	− 0.2	0.0	− 0.2	− 0.9	− 1.6	+ 2.8	+ 2.3	0.5	0.3
2.348	.863	.942	.940	.925	.951	.951	0.0	0.0	− 2.1	0.0	− 0.9	+ 0.9	− 3.3	+ 1.9	+ 5.0	0.0	0.0	0.7
Means.	......	......	......	......	......	......	− 1.2	− 0.6	+ 2.3	+ 0.5	− 0.3	− 0.5	− 1.1	+ 0.5	+ 0.4	− 0.6	0.9	0.3

Referring to Tables 2 and 11, and to Annals, Volume III, Table 47, the reader will see that the atmospheric transmission on September 20 and 21, 1914, was distinctly above the average, and indeed was as high as we have ever found on Mount Wilson. Secondly, the quantity of water vapor between the station and the zenith, as found by Mr. Fowle's spectroscopic method, was unusually small and satisfactorily constant. Hence, we may conclude that the two days in question were, as they appeared to the eye, days of the highest excellence at Mount Wilson. When we compare the results obtained from them on the solar constant of radiation, as given in Table 10, with those obtained in other years, as shown in Table 1 and in Annals, Volume III, Table 44, we see that the values were very close to the mean results of all our observations. We see further, from Table 10, that the results obtained were very nearly the same, whether we used only the later observations, taken between air mass 1.3 and air mass 4, as in our usual investigations; whether we employ only the observations between air mass 4 and air mass 12, as recommended by Mr. Very; or, finally, whether we take all the observations from air mass 1.3 to air mass 20. In every case the result is the same almost within the error of computing.

From this we feel ourselves fully justified in drawing the conclusion that our former work has not been vitiated by the employment of too small air masses, and that, in fact, hardly different results would have been obtained had we observed from sunrise of every day in which we have worked. On account of the uncertainty which attends the theory of the determination of air masses, when zenith distances exceeding 75° are in question, we conceive that it will be better to confine our observations hereafter, as we have generally done in the past, to the range of air masses less than 4, where the secant formula applies in all atmospheric layers, irrespective of optical density, refraction, or the earth's curvature.

Third objection.—We attach very little weight to any determinations of the solar constant of radiation which we have made hitherto, except those made by the spectrobolometric method developed by Langley, as just employed for September 20, 1914, and which is the definitive method employed by the Astrophysical Observatory of the Smithsonian Institution.[10] However, in Volume II of our Annals we showed in the second part of the work that the results obtained by this method

[10] Messrs. Very and Bigelow describe as "the spectrobolometric method" of determining the solar constant of radiation something quite different, viz: They take our determination of the form of the solar-energy curve outside the atmosphere. From this they determine the wave length of maximum energy, and from it they infer the temperature of the sun, supposing it to be a perfect radiator or "black body." They then determine the intensity of energy which a perfect radiator of the sun's size, and of the temperature which they thus decide upon, would give at the earth's mean distance. This value they regard as the solar constant.

In this determination they assume: Firstly, that our atmospheric transmission coefficients, which at other times they describe as altogether erroneous, do not distort the true form of the sun's energy curve outside the atmosphere; secondly, that our determinations of the transmission of the optical apparatus (and these we ourselves admit to be determinations of great difficulty, and only moderate accuracy) also do not distort the form of the energy curve; thirdly, that the position of the maximum of energy determines the proper temperature of the sun; fourthly, that the total emission of energy of the sun is the same function of its temperature that the total emission of a "black body" is.

We are far from wishing to discredit the substantial accuracy of our determination of the form of the sun's energy curve outside the atmosphere, but we totally dissent from these authors' application of it. In the first place, the form of the energy curve as determined by us does not agree with the form of the energy curve of a "black body" at any single temperature whatever. In the second place, if the temperature of the sun could be properly inferred from the consideration of the position of maximum energy in its spectrum, even then there would be no reason to suppose that the radiation of the sun bears the same relation to its temperature as the radiation of a "black body" bears to its temperature. Since the sun is not a "black body" of uniform temperature, it may depart widely from the conditions of such a "black body."

The same method could just as reasonably be applied to the radiation of a mercury-vapor lamp. The maximum of energy with such a lamp would be found in the green, as it is in the solar spectrum, and thereby, following Very and Bigelow, one could infer that the temperature of the lamp is of the order of six to seven thousand degrees absolute. Then, following still further our authors, we should assume that the mercury-vapor lamp, the sun, and the "black body" at, say, 6,800° would give equal intensities of energy, provided these three sources were of equal angular size. Thus the radiation of all three would be about 3.5 calories per cm^2 per min. The absurdity of this conclusion is apparent.

were harmonious with rougher ones obtained by considering terrestrial meteorological conditions. In the course of that discussion we used the data which were at that time available for determining the transmission through the moist atmosphere of the long-wave radiations such as the earth sends out. Mr. Very has confused that discusssion with our definitive determination of the solar constant of radiation, of which it forms no part at all. We do not care to discuss, at the present time, the coefficients for terrestrial radiation, as we are engaged in investigations of this matter which are not as yet completed. It has no bearing upon the definitive values of the solar constant obtained by us.

As for the dependence of the transmission of solar rays upon atmospheric water vapor, we have employed the hypothesis of Langley, namely, that there will be no water vapor outside the atmosphere. This gives us the highest results which can properly be reached. As we shall see in the conclusion of this article, our results obtained in this manner are supported by another line of investigation.

Fourth objection.—We perhaps do not understand just what Mr. Very has in mind in regard to this. Certainly there is no sheet of ice or anything of a continuous surface to be found in the air, so far as we know, which would answer to the description of the conditions referred to in the fourth objection. Some approach to it may be found in the case of a cloud. But we have repeatedly ascended from Pasadena to Mount Wilson through clouds, and even in this case we always perceived that the upper edge of the cloud had a gradual thinning out for at least many meters. We do not conceive that there is any other layer in the atmosphere for which this is not true. A transition extending through at least many meters is all that we require when we speak of a "gradual" change of transparency from one atmospheric layer to another.

As Mr. Very hints, there are irregularities in the distribution of the various bodies of air. For instance, in the neighborhood of a mountain there are currents of air of different temperatures rising and falling along the slopes. These, to be sure, do not fall into the horizontal layers postulated in our hypothesis of the atmospheric transmission, but they disturb the regular distribution in altitude so little relatively to the whole thickness of the atmosphere, and furthermore, the differences of atmospheric tranmission of these different bodies of air from their immediate surroundings are so slight, that their influence on the transmission coefficients which we obtain may be neglected.

Fifth objection.—We understand that it is here claimed that the general apparently nonselective losses to which the solar beam is subject in passing through the atmosphere are due not only to the scattering of radiation by particles small as compared with the wave length of light as indicated by Lord Rayleigh's theory, but also to a true absorption occurring in spectrum lines which are so fine as to have escaped discovery hitherto, although so numerous as to produce a profound effect upon the transmission of the atmosphere. Indeed, Mr. Very says in another place that one may prove that atmospheric losses in the atmosphere are at least three times as great as are indicated by Rayleigh's theory of scattering, or by the secant formula of extinction. We have found by balloon experiments, as we shall show, that the radiation at a level of about 25 kilometers, where more than twenty-four twenty-fifths of the atmosphere lies below, is still not greater than 1.9 calories per square centimeter per minute. Hence the condition of affairs referred to by Mr. Very, if it exists, applies only to the very highest layers of the atmosphere, exerting less than one twenty-fifth part of its pressure. Apparently, however, his strongest evidence of this supposed condition of affairs is his fixed impression that the solar constant must be greater than we have found it.

As to the effect on solar radiation of particles too gross to diffract the rays, this must refer to dust particles, or agglomerations of dust and other materials about nuclei of one kind or another, perhaps about the hydrols which are thought by some to exist in the atmosphere. In regard to this we have only to refer to that line of Table 2 which shows the transmission of the atmosphere for July 26, 1912, when it was filled with volcanic dust. The atmospheric transmission was then greatly reduced, but in a manner to make the sky white, not blue. Hence we may say that the particles composing the dust were large as compared with the wave length of light. But our values of the solar constant obtained both at Bassour, Algeria, and at Mount Wilson, California, did not differ appreciably from those we had obtained in the clearest of skies.

It is urged that there are diffuse bands of atmospheric absorption which have escaped detection, but which, if taken account of, would increase the value of the solar constant of radiation. We call attention here to the results published by Mr. Fowle[11] in which he determined in the ordinary manner, from Washington observations, transmission coefficients in the great infra-red water-vapor bands. These transmission coefficients, as he showed, sufficed almost, or quite, to obliterate these bands from the energy curve of the sun outside of the earth's atmosphere, just as they ought to do, if effective, seeing that no water vapor exists in the sun. If, now, there are other bands which are so inconspicuous that they can not be found without the most careful consideration of the atmospheric transmission coefficients, as indeed Mr. Fowle's researches on the relations of the transmission coefficents to Lord Rayleigh's theory of the sky light have shown, still their effects will be eliminated in the same manner as the infra-red bands were in the investigation just cited, because the transmission coefficients in such spectrum regions will be smaller than they would have been had the bands not been present there. We feel satisfied that the existence of such bands, even if there are any others than those which we

[11] Smithsonian Miscellaneous Collections, vol. 47.

know of, would hardly in the slighest degree influence the value of the solar constant of radiation.

Sixth objection.—In regard to this matter, we think Mr. Very has misinterpreted our procedure. We did not determine the quantity of energy contained in the extreme infra-red part of the emission of a "black body," of the size and distance of the sun, at 6,000° absolute temperature, and add that to what we have found from our spectrobolometric observations. On the contrary, our procedure has been to piece out the spectrobolometric curve as we have found it to be outside the atmosphere, by joining onto it, where our determination ends, a curve after the form of the distribution of energy computed by the Wien-Planck formula for the "black body" at 6,000°. If, now, the condition of the sun is such that its distribution of radiation in the infra-red corresponds to a "black body" at 7,000°, or some still higher temperature, then the real rate of the falling off of the curve in the infra-red, beyond the region that we observe, would be more rapid than that which we have assumed it to be. Accordingly the area included under such a curve would be less than we have assumed it to be, and thus our value of the solar constant of radiation will be too large on account of the error of our method of extrapolating in the extreme infra-red, rather than too small, as Mr. Very maintains. At all events, surely the difference so far down in the spectrum as this is altogether trifling in amount.

Seventh objection.—We agree with Mr. Kron that the ultra-violet spectrum may be a little more intense than we have supposed it to be. However, when we consider the rapid falling off of solar energy in the violet, and the reasonableness of it in view of the immense number of solar absorption lines and other solar circumstances, we see no probability at all that the part neglected would exceed 1 or 2 per cent, at most, of the value of the solar constant of radiation. In confirmation of this view, we point to the results of the balloon flights, which we shall shortly describe.

Eighth objection.—As Mr. Very, in a recent article, has shown that Mr. Bigelow's thermodynamic considerations are erroneous, it is not necessary to discuss them further.

SOUNDING BALLOON OBSERVATIONS.

Now we come to the final piece of experimental evidence which we have secured, which seems to us to show that our solar-constant results are undoubtedly very close to the true ones, and that if there be any circumstances which have led to the underestimation of the losses which the solar beam suffers in the atmosphere, they at any rate relate to the part of the atmosphere which lies beyond the altitude of 24 kilometers, and where the total pressure of it is less than one twenty-fifth of that which prevails at sea level.

In January, 1913, it was determined on the part of the Smithsonian Institution to support an expedition to California, in charge of Mr. A. K. Ångström, for the purpose of observing the nocturnal radiation at various altitudes. In connection with this work, the Institution invited the cooperation of the United States Weather Bureau for the purpose of sending up sounding balloons and captive balloons, in order to determine the humidity and temperature at various heights in the atmosphere, at the time of Mr. Ångström's experiments. While discussing the proposed expedition with Mr. Ångström, he inquired of us whether it might not be possible that an instrument could be devised for measuring the intensity of the radiation of the sun at the highest altitudes to be reached by sounding balloons. After due consideration of the matter, it was deemed by us feasible to do this.

Accordingly in the months of April, May, and June, 1913, there were constructed at the instrument shop of the Astrophysical Observatory, five copies of a special recording pyrheliometer, modified in form from the silver-disk pyrheliometer which we ordinarily employ in solar-constant work.

The five instruments were sent up, in cooperation with the United States Weather Bureau, by Mr. Aldrich, at Avalon, Santa Catalina Island, California, in July and August, 1913. All were recovered, and all had readable records of more or less value. In these experiments, the balloon in one instance reached the height of 33,000 meters, but unfortunately, owing to the freezing of the mercury contained in the thermometers, the pyrheliometric records did not extend above an altitude of 14,000 meters in any case. There were, besides, certain sources of error which had not been anticipated at that time, so that the results of the expedition could only be regarded as of a preliminary character. The results, such as they are, indicate radiation values not exceeding 1.8 calories per cm^2 per minute.

Early in the year 1914, we began to rebuild the instruments, which had been injured in their flights. On February 18, the preparations having been considerably advanced, Mr. Abbot wrote the following letter to Mr. Very, which is self-explanatory:

February 18, 1914.

Dear Mr. Very: As you know, we are interested in the value of the solar constant of radiation. We know that you are also. In our view this quantity lies between 1.9 and 2 calories per square centimeter per minute. In yours it lies between 3 and 4 calories or possibly higher. All measurements made by us rest on the "Smithsonian Revised Pyrheliometry of 1913." They are 3.5 per cent higher than they would be on Ångström's scale, as shown by numerous comparisons made in America and Europe. In the interests of ascertaining the truth, which I know to be your sole object, as it is ours, will you be so good as to answer these questions:

1. Do you consider the "Smithsonian Revised Pyrheliometry of 1913" as satisfactorily furnishing the standard scale of radiation?
2. If not, why not?
3. If in error, is it too high or too low, and how much?

I assume that you are not likely to think its results as much as 5 per cent too low, and that the discrepancy between your ideas of the solar constant and ours lies mainly outside of our conclusions as to the realization of the standard scale of radiation. In this posture of affairs, I propose to try the following experiments, which I hope will be crucial:

By cooperation with the United States Weather Bureau we propose to send up with balloons five automatic-registering pyrheliometers in June or July next. In preliminary experiments last summer the balloons generally reached 20 to 30 kilometers altitude, and in one case 33 kilometers. Mr. Blair expects personally to attend to the balloons this year, and hopes to get them all above 30 kilometers and some even to 40 kilometers. [This hope was disappointed, probably because the balloons used in 1914 were a year old.] These elevations are of course derived from barograph records, and it is not the elevation we care about, but the pressure of atmosphere above. This is given directly by the barographs, which will be calibrated, at the temperatures expected, by Mr. Blair. [Calibrations were finally made at the Smithsonian Institution.] We may expect the pressure reached will be less than 1 per cent of that at sea level. It is designed to make the pressure record on the same drum as the pyrheliometer record, so that there can be no error by differences of running of independent clocks.

I now come to a second group of questions.

4. Do you think that the intensity of the solar radiation in free space at the earth's solar distance is materially higher than that at a station within the atmosphere of the earth, where the barometric pressure is less than 1 per cent of that which prevails at sea level?

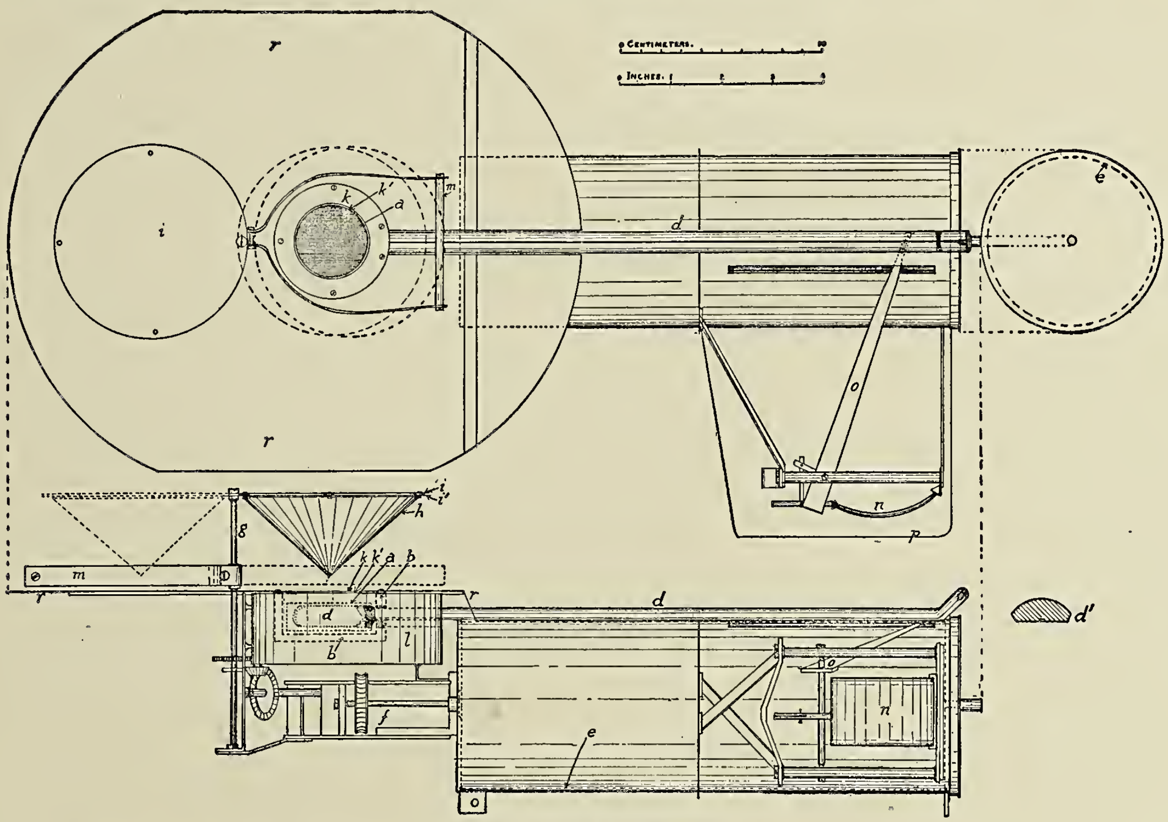

FIG. 53.—Balloon pyrheliometer.

5. If so, how much and why?

I assume that you do not think the radiation in free space would be as much as 5 per cent the higher of the two. If so, the proposed balloon experiments may be expected to be conclusive to you as well as to me, if you are satisfied as to their accuracy.

The apparatus is now in so forward a state of preparation that if you should be in Washington I hope you will do me the kindness to come and see it and discuss it. As that may be impracticable, I give the following details which may enable you to suggest sources of error which may be removed before the flights take place, or at least satisfactorily determined in advance by experiments.

This instrument is a modified form of our disk pyrheliometer. A blackened aluminum disk, *a* (fig. 53), incloses a thermometer, *d*, whose stem is shown in enlarged cross section at d^1. The cavity for the bulb of the thermometer within the disk, *a*, is filled up with mercury, and sealed at the mouth with thread and wax as in our pyrheliometers. The disk is inclosed in an interiorly blackened aluminum box, *b*. Two polished copper rings, *k*, k^1, limit the solar beam to a cross section less than that of *a*. As the temperature of the disk *a* changes, the mercury in the stem fluctuates, thus allowing the sun to print on more or less of the length of the photographic drum, *e*, according to the temperature. Thus, when the paper (solio paper) is removed, there is a record like this (see fig. 57):

A clock work *f* rotates the drum, and at the same time causes the shutter, *g h i* i^1, to be for four minutes in the position above the disk *a* as shown, then four minutes opened (as partially shown dotted at the left), then again closed as shown, and so on, rotating, at the end of each four minutes, 180° on *g* as an axis. The shutter comprises three parts. Of these *i* and i^1 are polished aluminum disks, and *h* a polished silver cone. The angle of the cone, *h*, is such that all rays from *a* must go either directly or by reflection to the sky, none to the earth. Hence when the shutter is closed the disk *a* observes the sky directly, or by reflection, though not the zenith sky. When the shutter is open the disk observes the sun plus the sky, at this time the zenith sky. Hence the difference between the radiation exchange when the shutter is open, or closed, is not entirely due to the sun, but in part to the difference between zenith and horizon sky, and to the imperfect reflection of silver. These differences are, however, not large, and they may be approximately determined. At high levels the sky light will diminish, and the difference of radiation exchange to surroundings (other than the sun) between shutter open and shutter closed may become very small indeed, compared to solar radiation. The shutter is made, when closed, to hide the sky to 30° zenith distance from all parts of the disk *a*, when the apparatus hangs as if suspended from the balloons. The apparatus is hung by a steel wire of nearly 25 meters length below the balloons.

In order to prevent the mercury in the thermometer from freezing, the cup *b* is wound outside and underneath with resistance wire, and batteries are taken along to heat the wire. Their action is automatically controlled by a curved strip of brass and invar *c* lying in a groove in the cup *b* and arranged to open against platinum points and complete circuit when the temperature of the curved strip goes below 0° C. [This arrangement was not used in the most successful flight, and is not shown in fig. 53.] The whole apparatus is covered with a blanket of black silk and down, excepting the top of the disk *a*, the shutter *h*, and the thermometer stem *d*.

Each instrument is to be repeatedly calibrated against silver disk pyrheliometers before sending it up, and the flights are to be made on cloudless days, and pyrheliometer readings taken on the ground during flight. A correction to the aperture for zenith distance of the sun will be made.

As stated above, similar experiments have already been made with considerable success in 1913. Records to 13,000 meters were obtained, but for lack of the heating apparatus above mentioned the mercury froze, and prevented higher records. Since then the apparatus has been wholly rebuilt with Richard clocks and the best possible driving mechanism, so that backlash of the drum is nearly eliminated.

Neither you nor I have read, or ever can read, the pyrheliometer outside the atmosphere. It is now proposed to cause automatic pyrheliometers to observe as high up as possible. In the interest of learning the truth, I beg that you will be so good as to suggest to me wherein the proposed experiments are likely to fail, so that all possible precautions may be taken against failure. Undoubtedly it will be impossible to get results to 1 per cent, but—

6. Do you see any reason why the experiments should not be decisive as between a solar constant of 1.9—2.0 calories and one of 3—4 calories?

I await with much interest your replies to my six questions, and any suggestions you may have the goodness to offer.

In response to this communication, Mr. Very was kind enough to send two letters which contain very valuable suggestions. We quote a portion of the letters as received:

(*a*) Without actually experimenting myself with such actinometric apparatus as you use, I should not care to express an opinion as to its efficiency.

(*b*) I regard the upper isothermal layer of the atmosphere as due mainly to local heating through absorption of solar radiation. Until we get above that layer, I should expect to find increment of solar radiation with each increase of altitude. It seems to me improbable that this limit will be reached at 40 kilometers.

(*c*) Any plan for a high level measurement of solar radiation which has even a small prospect of success may be worth trying. It is to be regretted that yours involves the local application of electric heating, which seems to me very risky and liable to produce all sorts of complications and unforeseen results. * * * I would suggest that ascension should be made at night with a little electric lamp, to give the record, to see what sort of a record you would get when the sun is away. The combination of night and day records might enable you to eliminate some errors inevitable in the method. * * * If your disk and its attachments are too massive, four minutes' exposure may not be long enough. You can not use a very long exposure because the balloon ascension ends too soon. It behooves you therefore to have your thermometer and disk made on the smallest possible scale. Another thing which may be unavoidable in your construction is the very circumscribed protecting case. The same instrument may read differently in a wide, roomy case. * * * The knowledge of how such an apparatus as you are proposing will behave in the absence of the sun seems to me almost indispensable. Thus I should be apprehensive that the interpositions of the metal cone above the heat-measuring disk will act as a wind shield to some extent. There will, therefore, be less cooling from contact with the air during shade than there would be if the wind effect were constant, and the fall of temperature in shade will be too small in the day observation. At night there might even be a rise of temperature when the cone is interposed, and it is desirable to learn whether this is so, and the amount of the change. * * * During the most rapid part of the ascent, the instrument is exposed to a strong resultant air current, which may exceed 7 meters per second. This powerful wind blowing directly upon the face of the instrument must tend to keep it at air temperature, and will diminish the effect of the sun's rays. During calibration, steady, artificial, vertical air currents, of 1 to 10 meters per second, should be made to impinge upon the face of the instrument, and the results tabulated in comparison with the record of a standard instrument not thus affected. It is partly on account of this strong downward air current that I do not approve of your shallow cup, because this construction allows nearly free access of air currents to the heated surface, which is liable to work great harm to the observations unless corrections are determined from elaborate researches. * * * I like the principle of the Violle actinometer, namely, that of a wide, encompassing jacket at constant temperature; and although some sort of a compromise must be made in your case, it might be better to use a broader disk (even though this diminishes the sensitiveness of the arrangement) and to place this disk at the center of a double-walled alcohol jacket several inches in diameter. This will surely diminish the wind effect, although I should still want to calibrate the thing with the same strong downward currents as noted above. * * * By rights the temperature of the alcohol jacket should be recorded as in Violle's instrument. This would require another thermometer, and a duplicate registering apparatus. With an alcohol jacket the mercury thermometer would work down to nearly $-40°$ C, and, with the greater protection of a circumscribed aperture and partial shielding from the wind, I should suppose that the apparatus might continue to register when the outside air is quite a little colder than this. But here I am only guessing, and there is the same objection to doing that in the present case as there is to answering your "six questions." I prefer to leave the guessing to you, and only say: Try it. And I wish you success.

In view of Mr. Very's excellent suggestions, four of the instruments were arranged to be used by day, and one, with a row of electric lights above the thermometer for recording purposes, was arranged to be sent up at night. In two of the day instruments the proposed electric heating was dispensed with. In place of it there was substituted a chamber of water (*l*, fig. 53), completely inclosing the sides and bottom of the aluminum cup, within which is placed the aluminum disk. A large number of copper strips for conducting heat were disposed in all directions through the water chamber, and soldered to the inside wall of it, so as to bring the water in intimate thermal conductivity with the immediate surroundings of the aluminum disk. Thus it was hoped to make use of the latent heat of freezing of the water, so that, in fact, the water jacket would act as a constant temperature case, to prevent the cooling of the thermometer below the freezing point of water. This worked excellently.

A change was made from the practice of 1913 in attaching the barometric element as a part of the pyrheliometer, instead of sending up a separate meteorograph. Barometric elements, loaned by the Weather Bureau, were mounted as shown at *n*, figure 53. The light aluminum arm, *o*, passing through a slot in the side of the cover cylinder, rests upon the photographic paper on the drum, *e*, between the thermometer, *d*, and the drum. A little longitudinal slot is cut in the aluminum arm, *o*, at the point where it passes under the thermometer, so that, as the drum revolves, the sun prints through the thermometer stem and the slot, and makes a trace of the position of the arm, *o*, appearing as a dark narrow streak between two light streaks.

No temperature record was obtained in the pyrheliometer flights of 1914. Certain corrections to the barometric readings depending on the temperature were worked up by a consideration of the temperatures found in other flights, as will appear in its place. It would have been better if the mounting of the barometric element had been wholly of invar, so as to reduce these corrections, but no essential harm seems to have resulted.

The size of the apparatus was made as small as seemed practicable, and its entire weight, including about one-half pound of water but exclusive of silk, feathers, and cotton used for wrapping, was only 3 pounds for the water-jacketed instruments. The electrically heated instruments, with their battery [12] and devices for operating it, weighed about 4 pounds.

METHOD OF READING PYRHELIOMETER RECORDS.

The records indicate the rate of rise of temperature of the aluminum disk during exposure of it to the sun, and the rate of fall of temperature of it during shading. One desires to know the rate of rise during exposure as it would be if there were no cooling due to the surroundings. In reading a record, it was fastened upon a large sheet of cross-section paper, with the degree marks of the balloon pyrheliometer record lying parallel to the section lines, in abscissæ. A fine wire was then stretched parallel to a branch of the zigzag trace, and the tangent of its inclination to the degree marks was read upon the cross-section paper. Each

[12] A special form of Roberts cell was developed, comprising tin, nitric acid, and carbon. Each cell was of 20 grams weight, 1.3 volts potential, and furnished an average of 0.4 ampere for 2 hours.

such tangent was determined by several readings. The tangent representing each solar heating was then corrected by adding to it the mean value derived from the coolings preceding and following it. Thus we obtained, in arbitrary units, values proportional to the solar heatings. The same method of reading was applied to the records obtained while calibrating the balloon pyrheliometer, at Omaha, and at Washington, before and after the flight, against standardized pyrheliometers, and so the results were reduced to calories per cm^2 per minute.

SOURCES OF ERROR.

1. EFFECT OF AIR CURRENTS.

In relation to the important point raised by Mr. Very regarding the effect of a downward current of air, a balloon pyrheliometer was calibrated in a current

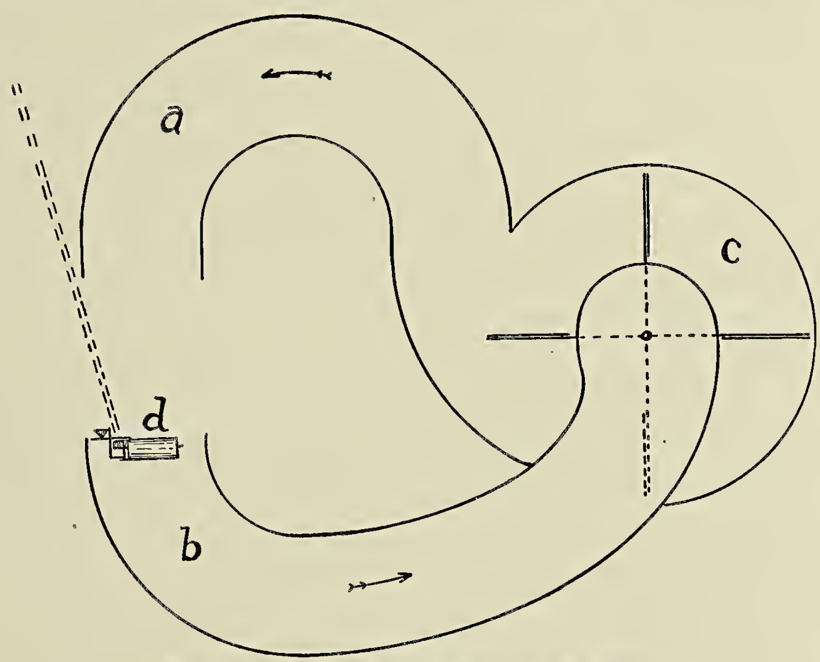

FIG. 54.—Testing the balloon pyrheliometer in air currents.

of air. The method of doing this is shown in figure 54, in which *a b* represents a 20-inch pipe connected to the blower *c*, and causing the current of air of known velocity to pass over the balloon pyrheliometer *d*. In this situation the balloon pyrheliometer was compared, with and without flow of air, with the standardized silver-disk pyrheliometer. The rate of flow of the air was taken at 5 meters per second, which would be the maximum rate of ascent of the balloon during its flight.

The results of these experiments were surprising to us, for we had assumed, with Mr. Very, that the effect of the downward current of air would be to increase the rate of cooling of the aluminum disk when the shutter was open. The contrary appears to be the case, for the corrected readings of the balloon pyrheliometer were, at the first, about 16 per cent higher when the current of air was in operation than when read in still air.

We reduced this source of error very greatly, by attaching to the instrument a flat plate of blackened tin (*r*, fig. 53), level with the copper ring diaphragms which admit the light to the aluminum disk, and extending out from the copper disk to about 25 centimeters in diameter. This tin plate deflected the current of air in such a manner that the magnitude of the error we had found became reduced to 4 per cent. It seemed to us that the error must be proportional to the number of molecules carried down by the current of air, and that it would therefore decrease directly in proportion to the pressure of air in which the instrument found itself. Accordingly we believe that at the altitude reached by the instrument, namely, 24 kilometers, where the pressure of the air is only one twenty-fifth of that which prevails at sea level, the effect of this source of error will be to increase the reading of the pyrheliometer by only about 0.2 per cent.

2. VARIATIONS IN SKY EXPOSURE.

As indicated in Mr. Abbot's letter, there was expected a difference in the radiation exchanged by the instrument with the sky, depending upon whether the shutter is opened or closed. This difference grows less and less as the instrument goes to higher and higher altitudes, but there could readily be a source of error here if the instrument were compared on the ground with another instrument exposing the disk very differently.

To avoid this source of error, one of our older pyrheliometers, No. V, was reconstructed, so that it might be exposed to the sun and sky in exactly the same manner as the balloon pyrheliometer. In fact, one of the balloon pyrheliometers was taken to pieces and the copper diaphragms and the shutter were transferred to pyrheliometer No. V, so that, in respect to its exposure, pyrheliometer No. V became identically similar to the balloon pyrheliometer No. 3. The two instruments were then compared, and the result of the 16 determinations gave us the ratio of their readings: $\frac{\text{No. 3}}{\text{No. V}}=1.882\pm0.024$. We then returned pyrheliometer No. V to its original condition, except that we retained the same copper diaphragms, so as to prevent any error from the measurement of the size of the aperture; and we compared it with silver-disk pyrheliometer No. 9. By 14 comparisons we determined the constant of pyrheliometer No. V in these circumstances to be 0.849 ± 0.003, to reduce its readings to calories per cm^2 per minute. From this we find the constant of balloon pyrheliometer No. 3 to be 0.451 ± 0.006.

In this way, it appears to us, the source of error above mentioned was avoided. A few comparisons were also made at Omaha directly between balloon pyrheliometer No. 3 and silver-disk pyrheliometer No. 9. These show the magnitude of this error, for assuming that no such error as above considered exists, the results of these comparisons yield for the pyrheliometer No. 3 the constant 0.414, which differs by 8 per cent from the value obtained by the preferred process.

3. ROTATION OF THE INSTRUMENT.

Another source of error which was not inconsiderable depended upon the rotation of the balloon during its flight, for the instrument not only rotated, but swung around a small cone, so that the average angle made by the sun rays with the surface of the aluminum disk was not given immediately by a knowledge of the latitude of Omaha and the declination and hour angle of the sun at the time of exposure. Fortunately the record of the flight gave means of determining this small correction. The record of the degrees marked upon the thermometer stem, instead of being a series of parallel fine lines as they are shown in figure 57, became broadened out as the instrument rotated. By measuring the distance apart of the edges of the broadened lines, as compared with results found in check experiments made by moving the instrument through known angles, the half angle of the cone during the highest part of the flight was determined and found to be about 9°. It was then computed that a correction of about 1.2 per cent should be added to the readings over and above that of about 8 per cent which was due to the zenith distance of the sun.

4. RATE OF THE CLOCKWORK.

At Omaha, on July 2, 1914, during calibrations, the mean period occupied by a complete rotation of the shutter was found $8^m\ 17^s$; at Washington, on December 26, 1914, during calibration, $8^m\ 18^s$. Other records give similar indications of substantial constancy of rate of the clockwork. However, on February 4, 1915, at +19° C, the mean rate of the drum was 0.02154 mm per second while at −46° C, the mean rate found was 0.0217 mm per second. This indicates a change of 1 per cent for the range of temperature +34° to −37°, which occurred on July 11, 1914. This error would tend to diminish the results by 1 per cent.

5. HORIZONTAL THERMOMETER STEM AND CALIBRATION.

A difficulty was encountered in the experiments of 1913, for, owing to the horizontal position of the thermometer stem, the mercury thread sometimes separated, and failed to return after a rise of temperature. This was overcome by drilling a hole into the upper bulb, just before the flight, so that air pressure came upon the mercury column. In 1913, this worked perfectly satisfactorily, but in 1914 the mercury column became foul in every case but that of No. 5 pyrheliometer, owing probably to the creep of the lubricant used in drilling the glass. This prevented the use of pyrheliometers Nos. 1 and 2, and required several washings with benzol and alcohol before the bores of Nos. 3 and 4 were clean enough to be used. Even then the upper temperatures were unavailable, so that no use could be made of records at low altitudes in the flights of July 9 and July 11, 1914.

The reader will perhaps wonder why there was not left a small gas pressure above the mercury column in the original construction. This was not done, for we were required to calibrate the thermometer stems because their bores were not uniform. We could most readily do so by breaking the mercury thread and moving a short column from place to place in the bore, observing its length changes. This we did for all the thermometers, and have corrected our results accordingly. In view of our experience we should now prefer to introduce gas pressure in the original construction, and calibrate the thermometers in baths of known temperatures.

6. OTHER CORRECTIONS.

The aluminum disk, during the highest flight, differed slightly in its mean temperature from that which it had during calibration. Owing to change in the specific heat of aluminum with change of temperature, a correction of 0.5 per cent should be deducted for this.

The suspending wires in their rotation shaded the disk. A correction of 0.2 per cent should be added for this.

Variations in the absorption of the disk by deterioration of the blackened surface between July and December are thought to require a correction of somewhat less than 1 per cent to be deducted.

Variations in reflecting power of the copper diaphragms used in the calibrations are thought to require an additive correction of 0.25 per cent.

While the effect of the downward current of air seems to be nearly negligible, as indicated above, it may be possible that the considerable difference of temperature between the disk and the air during recording at highest altitudes tended to alter or change the sign of this error.

In consideration of all circumstances, it seems to us that the various small positive corrections, including the error below mentioned in determining the angle of the cone of rotation, but not that for clock rate or for inclination, may be regarded as balancing the various small negative corrections. We consider, therefore, in what follows, only the direct results of the exposures, the calibration at Washington, the correction for effective solar zenith distance, the correction to mean solar distance, the correction for clock rate, and the probable correction to reduce to outside the atmosphere.

CIRCUMSTANCES OF OBSERVATION.

The following circumstances attended the balloon pyrheliometer flights at Omaha: Observers: For the Smithsonian Institution, L. B. Aldrich; for the United States Weather Bureau, Dr. Wm. R. Blair, B. J. Sherry, and Mr. Morris.

India rubber balloons, imported by the Smithsonian Institution from Russia in July, 1913, were used. They were 1.25 meters in diameter, inflated with hydrogen gas, and were sent up in groups of three attached as shown in figure 55.

It was expected that after two of the balloons had burst by expansion, at high altitudes, the third would bring down the apparatus in safety. A reward was offered for the safe return of the apparatus by the finder.

In addition to the barometric element, as a means of measuring heights reached, the balloons were observed by two theodolites, separated by a known base line.

JULY 1, 1914, NIGHT ASCENSION.

Balloon launched with No. 5 pyrheliometer at $11^h\ 26^m$ p. m. in clear sky. Moon half full and setting. Wire, 22 meters long, plus 3 meters, plus 2 meters. Total, 27 meters. Electric flash light attached, but could be followed only a few minutes with theodolite at Fort Omaha, and was not seen from the second station. The apparatus was found July 3, 6.30 a. m., at Harvard, Iowa, two balloons still inflated. The instrument was somewhat damaged, but the record not harmed.

JULY 9, 1914.

Balloon launched with No. 4 pyrheliometer at $10^h\ 8^m$ a. m. Balloons followed by theodolites at both stations for $1^h\ 5^m$, and at one station for $2^h\ 16^m$. One balloon burst after 42^m, another after $2^h\ 4^m$. The apparatus was found at Omaha after 20 days, but the record was spoiled by light and water, and the instrument greatly damaged.

JULY 11, 1914.

Balloon launched with No. 3 pyrheliometer at $10^h\ 30^m$ a. m. Sky fairly clear, save for cirri near the horizon. All clear near the sun. Balloons followed by theodolites at both stations for 35 minutes, and at one station for over two hours. Two balloons burst nearly simultaneously, after $1^h\ 47^m$. Pyrheliometer A. P. O. 9 was read immediately after the launching as follows: At $10^h\ 35^m$, 1.147 calories; at $10^h\ 39^m$, 1.161 calories. Apparatus found $3\frac{1}{2}$ miles northwest of Carson, Iowa, on July 11, at 5 p. m., and received entirely uninjured at Mount Wilson, California. It was later carried uninjured to Washington, and tested in various ways during the following winter.

Weights of apparatus and accessories:

	Grams.
Three balloons, at 2,880 grams each	8,640
Pyrheliometer	1,250
Water in jacket	170
Silk, feathers, and cotton wrapping	370
Wire	50
Total	10,480

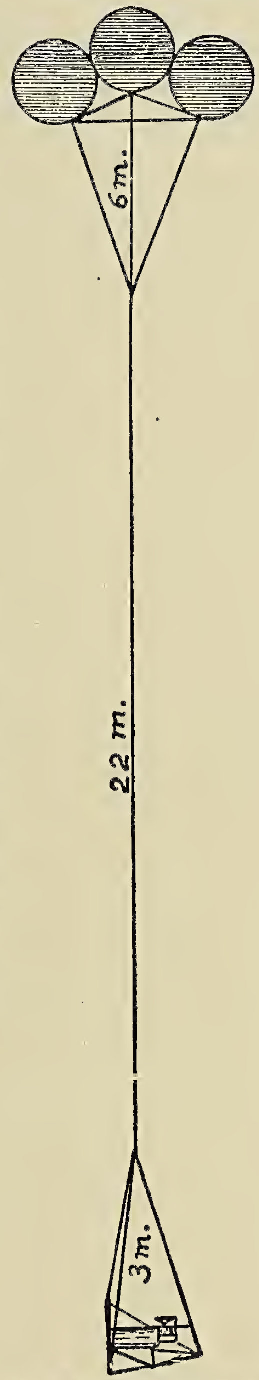

FIG. 55.—Method of suspending balloon pyrheliometer.

DISCUSSION OF RECORDS.

I. THE NIGHT RECORD.

In figure 56 is given a reproducion of the record obtained in the night flight made at Omaha on July 1, 1914. $A_1 A_2 A_3 A_4$ is the barometric record, $B_1 B_2 B_3$ the pyrheliometer record. As shown, the lighting current was cut off intermittently to prevent premature exhaustion of the battery. Unfortunately the mechanism failed to make electrical contacts in the region A_2 A_3, so that the pyrheliometer record is missing there. It does not show in the last part of the record corresponding to A_3 A_4, from which we infer that the electrical heating proved insufficient to hold the temperature of the disk above about —15°, corresponding to the position C, and that the record is lost in stray light somewhere below C. But from B_2 to B_3 is a period of 20 minutes, during which there were $2\frac{1}{2}$ complete rotations (5 swings) of the shutter, and the apparatus rose about 3,000 meters.

Apart from the slight fall of temperature shown at B_2, when the instrument was removed from the balloon shed, there is no appreciable sudden change of temperature, but only the gradual march attending increasing altitude. No periodic

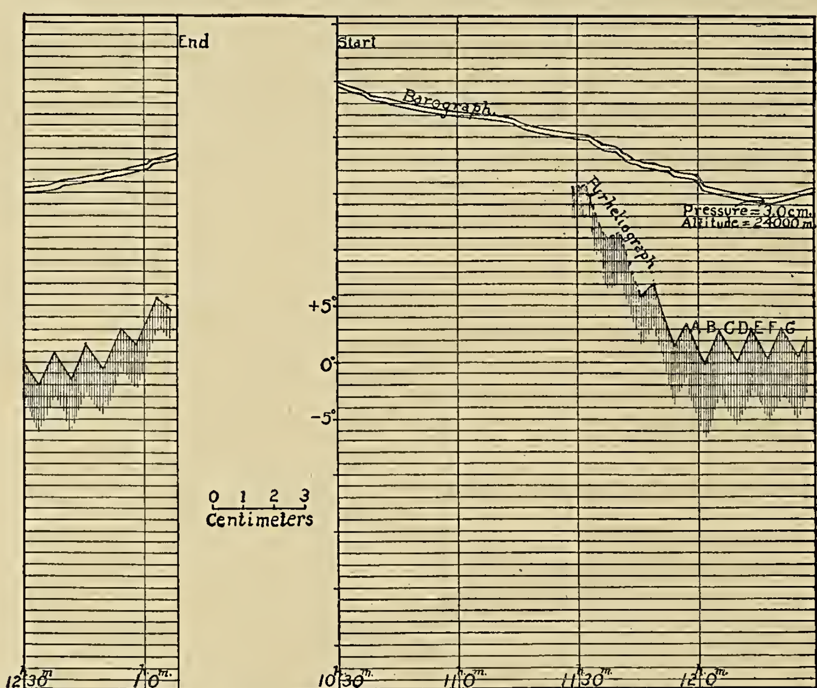

FIG. 57.—Balloon pyrheliometer record, July 11, 1914 (from a tracing).

change attributable to the opening and closing of the shutter is discernible. From this we conclude that no considerable error is caused by the current of air due to the uprush of the balloons, which it was thought might cool the disk unequally, depending on whether the shutter is open or not.

2. THE DAY RECORD.

The record obtained in the day flight of July 11, 1914, was on solio paper. It was read up while still unfixed, and was at that time very clear and good. Unfortunately it was submitted to the process of toning, without being first photographed, and became so faint that it is quite impossible to reproduce it, although it is still readable. Accordingly we give merely the readings made upon the original, and their reduction. Figure 57 is from a tracing made to represent the march of the record.

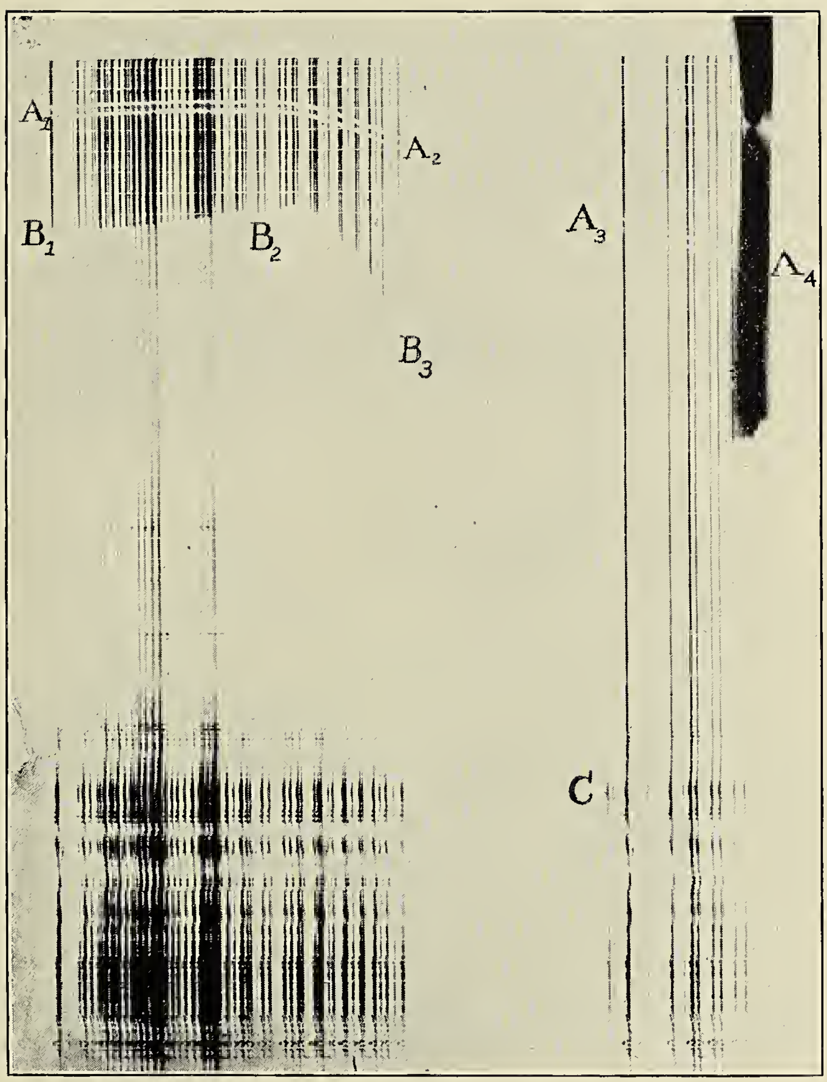

FIG. 56.—NIGHT RECORD WITH BALLOON PYRHELIOMETER.

The pyrheliometer record consists of a series of zigzag reaches of shading corresponding to the up and down marches of the mercury column. We shall principally confine attention to those marked *A, B, C, D, E, F, G,* which represent the solar radiation measured just before the instrument reached maximum elevation. We do this because: (1) As stated above, the earlier part of the records is of little value owing to the bore of the thermometer being foul for temperatures above +10°. (2) A defect in the record occurs just after the balloons began to descend, first owing to a jerkiness, and then owing to crossing the seam in the paper, which renders the next two following readings doubtful. (3) There is doubt as to the elevation at the time of the last descending records, because the barometer arm did not work quite free. (4) The record is finally lost in clouds. All readable records are, however, given for what they may be worth.

CORRECTION TO REDUCE TO VERTICAL SUN.

The extreme width of the degree marks on the record during heating *B, D, F,* was measured and found 1.40 millimeters. Inclining the pyrheliometer, first 15.5° N., then 15.5° S., when exposed to the sun, was found to shift the degree marks through a total range of 0.89 mm. Subtracting width of trace, 0.31 mm, and dividing by 2, we find the record sheet is within the pyrheliometer at a distance X, such that X tangent $15.5°=0.29$ mm. Hence $X=1.04$ mm. From this it follows that the tangent of the half angle of the cone swept through by the sun rays was $\frac{1.40-0.31}{2\times 1.04}$. Hence the half angle of the cone is 27° 40′. At Omaha, on July 11, at noon the sun's zenith distance was 19° 5′. Hence the pyrheliometer was swinging in a cone whose half angle was $27° 40' - 19° 5' = 8° 35'$.

From these data it follows that the mean value of the cosine of the inclination of the sun's rays upon the pyrheliometer disk at noon was 0.934. But if the instrument had been stationary this value would have been 0.945. Hence the conical rotation produced a change of 0.011. This value has been applied as a correction to the values of cosine Z, corresponding to the several sun exposures. It is probable that the correction is a little too small, because the record of the degree marks is naturally less wide than it would have been if time had been allowed for full photographic effect at the extremes of the swing.

TABLE 12.—*Balloon pyrheliometer observations.*

Readings on best three records of July 11, 1914.

Cooling A.	Heating B.	Cooling C.	Heating D.	Cooling E.	Heating F.	Cooling G.
2.53	1.34	1.78	1.90	1.96	2.10	1.65
2.22	1.45	1.77	1.78	1.86	2.00	1.53
2.39	1.33	1.84	1.77	1.97	1.90	1.40
2.64	1.50	1.88	1.75	1.92	1.98	1.50
2.40	1.34	1.90	1.88	1.82	1.82	1.61
2.55	1.52	1.91	....	1.84	1.78	....
Means 2.45	1.41	1.85	1.82	1.89	1.91	1.54
	2.15	....	1.87	....	1.715	....
Corrected heating	3.56	....	3.69	....	3.625	....

TABLE 12.—*Balloon pyrheliometer observations*—Continued.

Summary of readings and reductions.

Watch time.	Corrected hour angle, east.	Cosine Z.	Cosine Z corrected for rotation.	Pyrheliometer reading.	Reading $X \frac{0.451}{\cos z}$.
h. m.	*h. m.*				
11 55	0 34	0.936	0.925	3.56	1.736
12 04	0 25	.940	.929	3.69	1.791
12 12	0 17	.942	.931	3.625	1.756
12 20	0 09	.943	.932	3.225	1.561
	West.				
12 36	0 07	.945	.934	3.11	1.501
12 44	0 15	.944	.933	3.58	1.730
12 52	0 23	.941	.930	3.09	1.499

The solar radiation indicated by the mean value of the first three records, which are by far the best, is 1.761 calories per cm^2 per minute. Reduced to mean solar distance and adding 1 per cent for clock rate, it becomes

1.84 calories per cm^2 per minute.

As will be shown, the mean altitude at this time was about 22,000 meters, and the corresponding pressure about 3 centimeters. In our opinion an increase of about 2 per cent would be a proper allowance for the extinction in the atmosphere above this altitude, considering atmospheric scattering as 1 per cent, and atmospheric absorption 1 per cent.

BAROMETRY AND ALTITUDE.

The following results are given by the observations of the United States Weather Bureau, as indicated in communications quoted:

UNITED STATES DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU, OFFICE OF THE CHIEF,
Washington, D. C., March 15, 1915.

Dr. C. D. WALCOTT,
Secretary, Smithsonian Institution, Washington, D. C.

DEAR SIR: Replying to your letter of March 13, 1915, no readings of pressure and temperature were taken preceding the morning ascension of July 11, 1914. However, a reading was taken after the ascension, at 1 p. m., and another just preceding the second ascension, at 4 p. m. These readings were:

	Pressure.	Temperature.
At 1 p. m.	732.5 mm.	32.3° C.
At 4 p. m.	732.0 mm.	33.1° C.

The values at the Weather Bureau station in Omaha at these hours were:

	Pressure.	Temperature.
At 1 p. m.	730.8 mm.	35.6° C.
At 4 p. m.	730.2 mm.	35.6° C.

Applying these differences, +1.8 mm for pressure and −2.8° C for temperature, to the value at 10.30 a. m. at Omaha, viz. 731.5 mm and 32.2° C, we get 733.3 mm and 29.4° as the probable values at Fort Omaha just preceding the first ascension, or 10.30 a. m.

Very respectfully,

C. F. MARVIN,
Chief of Bureau.

United States Department of Agriculture,
Weather Bureau, Office of the Chief,
Washington, D. C., March 9, 1915.

Dr. C. D. Walcott,
Secretary, Smithsonian Institution, Washington, D. C.

Dear Sir: I inclose herewith the data for July 11, 1914, requested by you in your letter of January 29, 1915. They include, for the first ascension, when the balloon pyrheliometer was taken up, altitudes each minute as long as the balloons could be observed at both stations; for the second ascension, in the afternoon, temperatures at those levels in which the temperature-altitude relation changed, and interpolated values at 500-meter levels up to 5,000 meters, and at 1,000-meter levels above 5,000 meters. Pressures also are given, wherever it was possible to compute them. A considerable portion of the record has been rubbed off, by reason of its having lain in a mud pond for some days. There were several pounds of mud in the instrument when it was received. All altitudes were computed from the two-station theodolite observations.

The ascensional rates for the two ascensions are almost identical up to 6,000 meters. Assuming that they continue in this relation, a curve extended for the first ascension, as shown in the accompanying chart [not here shown], indicates an altitude of 25,600 meters at the time one of the balloons burst.

Very respectfully,

C. F. Marvin,
Chief of Bureau.

Table 13.—*Temperatures at different altitudes in balloon ascension, July 11, 1914, p. m.*

Time.	Altitude.	Pressure.	Temperature.	Remarks.
p. m.	*m.*	*mm.*	° *C.*	
4:02	312	732.0	33.1	Balloon launched.
....	500	....	33.2	
4:04.4	631	706.4	33.3	
4:07.3	962	681.0	29.8	
....	1,000	....	29.7	
4:11	1,503	640.1	26.0	
....	2,000	....	21.7	
4:18.2	2,493	....	17.5	
....	3,000	....	14.0	
....	3,500	....	10.8	
4:25.3	3,645	....	9.9	
....	4,000	....	9.6	
4:28.8	4,447	....	9.1	
....	4,500	....	8.6	
4:32.2	4,976	431.5	4.8	
....	5,000	....	4.7	
....	6,000	....	− 1.7	
....	7,000	....	− 7.9	
4:44.1	7,592	309.9	−11.5	
....	8,000	....	−13.4	
4:46.8	8,597	280.5	−16.0	
4:49	8,930	265.3	−17.9	
....	9,000	....	−18.3	
....	10,000	....	−24.8	
4:55.1	10,442	220.3	−27.6	

TABLE 13.—*Temperatures at different altitudes in balloon ascension, July 11, 1914, p. m.*—Continued.

Time.	Altitude.	Pressure.	Temperature.	Remarks.
p. m.	*m.*	*mm.*	°*C.*	
....	11,000	....	−31.8	
5:01.8	11,572	185.5	−35.9	
....	12,000	....	−38.7	
....	13,000	....	−45.2	
5:08.7	13,348	145.5	−47.0	
....	14,000	....	−48.8	
5:13.7	14,641	....	−52.0	Lowest temperature.
....	15,000	....	−51.5	
5:15.7	15,026	....	−51.5	
5:19.2	15,457	....	−48.3	
....	16,000	....	−48.3	
5:22.4	16,855	....	−48.3	
....	17,000	....	−46.6	
5:24.3	17,106	....	−45.2	Clock stopped.
5:28	18,164	....	....	Balloon burst.

TABLE 14.—*Altitudes of balloon, determined from theodolite readings at two stations, July 11, 1914, a. m.*

Time.	Altitude.	Remarks.
a. m.		
10:30.3	312	Balloon launched.
10:32	720	
10:33	1,016	
10:34	1,286	
10:35	1,392	
10:36	1,606	
10:37	1,760	
10:38	1,900	
10:39	2,022	
10:40	2,166	
10:41	2,280	
10:42	2,424	
10:43	2,585	
10:44	2,688	
10:45	2,898	
10:46	2,982	
10:47	3,178	
10:48	3,358	
10:49	3,568	
10:50	3,718	
10:51	3,876	
10:52	3,970	
10:53	4,159	
10:54	4,270	
10:55	4,528	
10:56	4,682	

TABLE 12.—*Altitudes of balloon, determined from theodolite readings at two stations, July 11, 1914, a. m.*—Continued.

Time.	Altitude.	Remarks.
a. m.		
10:57	4, 950	
10:58	5, 052	
10:59	5, 122	
11:00	5, 218	
11:01	5, 538	
11:02	5, 492	
11:03	5, 825	
11:04	6, 122	
11:05	6, 006	Balloon disappeared from view of observers at Creighton College.
p. m.		
12:17. 7	....	Balloon burst.

CALIBRATION OF THE BAROMETRIC RECORD OF JULY 11, 1914.

This record is marred by the sticking of the aluminum arm at middle deflections, both in rising and falling flight. Fortunately the arm appears to have been free at maximum elevation, as shown by the perfectly normal inflection of the record at precisely the time when the two balloons were observed to burst. Accordingly, while no suspicion attaches to the record at maximum elevation, it is worthless at intermediate elevations.

The barometer element was calibrated by inclosure of the whole instrument in a brass box from which air could be exhausted, and of which the temperature was regulated by immersion in a stirred bath of gasoline cooled by expansion of liquid carbon dioxide. In one set of experiments the sensitiveness of the element to change of pressure was determined at several constant temperatures ranging from +34° C to −49° C, and the change of zero with change of temperature was determined as a correction. In another set of experiments, both temperature and pressure were simultaneously lowered to correspond with the temperatures and pressures indicated by the foregoing results of the Weather Bureau observers.

We assume that at the time of launching at Omaha, the instrument, being shone upon by the sun, was 5° in excess of the air temperature, and hence at +34° C. We assume that at the maximum elevation the instrument was at −37° C.

From experiments of December 26, 1914, and February 1 and 4, 1915, we find that the zero of the barometric element changed linearly at the rate of 0.123 mm per degree, in the sense to diminish the barometric deflection attending falling pressure. Hence for a fall of 71° the correction is 8.7 mm.

From the record of July 11, 1914, the barometric deflection is 37.8 mm at highest altitude. Corrected deflection, 46.5 mm. From numerous experiments at various constant temperatures, 76.4 cm mercury pressure corresponds to a deflection on our record of 50.3 mm. Hence for July 11, 1914, the change of pressure was $\frac{46.5}{50.3}\times 76.4=70.7$ cm Hg. The barometer reading at Fort Omaha was 73.33 cm. Hence, by these experiments, the pressure at maximum elevation was 2.63 cm Hg.

Again, on March 18, 1915, a change of pressure of 72.3 cm Hg., and accompanying change of temperature from $+34.8°$ to $-30°$,[13] gave a barometric deflection of 40 mm. Hence, from $+34°$ to $-37°$ would have given a deflection of 39.1 mm. Hence, the change of pressure on July 11 was $\frac{37.8}{39.1}\times 72.3=70$.

Hence, by these experiments the pressure at maximum elevation was 3.33 cm Hg. As a mean result, we decide that at maximum elevation the barometric pressure was 2.98 cm Hg., or in round numbers, 3.0 cm Hg. From our examination of the records of various balloon flights at Omaha and Avalon, we suppose this would be regarded as corresponding to an elevation of 24,000 meters, which is in good agreement with the results obtained by theodolite work.

COMPARATIVE RESULTS OF PYRHELIOMETRY AT REDUCED ATMOSPHERIC PRESSURES.

In a recent publication, Prof. H. H. Kimball gives the highest value of solar radiation ever observed at Washington, for zenith distance 60°, as 1.51 calories per cm ^{2} per minute, observed on December 26, 1914. Reduced to vertical sun and mean solar distance, this result would have been about 1.58 calories.

The highest values observed on Mount Wilson are those of November 2, 1909, and yield to a similar reduction 1.64 calories, at mean solar distance and vertical sun.

For Mount Whitney, for the maximum obtained on September 3, 1909, the reduced value is 1.72 calories at mean solar distance and vertical sun.

In balloon flights of August 31, September 28, and October 19, 1913, Dr. A. Peppler, of Giessen, observed with an Ångström pyrheliometer at great altitudes. On September 28 the results were, in his opinion, vitiated by a defect of the apparatus. On August 31, the highest result, as reduced by Peppler to the Smithsonian scale of pyrheliometry, was 1.77 calories, obtained at zenith distance 45°, altitude 5,900 meters, air pressure 36.5 cm. This result, however, is not a complete Ångström measurement depending on "left, right, left" readings, and therefore may be vitiated by galvanometer drift. Moreover, it stands very high as compared with others of that date, and, indeed, much higher than others of that date obtained at greater altitudes. On October 19, the highest complete result was 1.67 calories, obtained at zenith distance 61°, altitude 7,500 meters, air pressure 29.8 cm. This result is in good agreement with the others of that date. Peppler regards the results of October 19 as his best. When reduced to zenith sun and

[13] Here the carbon dioxide used for cooling purposes was exhausted.

mean solar distance, the result of October 19 comes out about 1.755 calories per cm ^{2} per minute.

These direct observations from manned balloons are very meritorious, and of course entitled to far greater weight than those obtained at similar altitudes in our free balloon work at Avalon, in 1913. Hence, although our results there were in complete accord with Peppler's, we have not thought it worth while to give them. Peppler intended to repeat the work in 1914 at greater altitudes, but we fear this may have been one of the valuable things cut off by war.

In figure 58 we give a plot of the pyrheliometer results at various altitudes, as just collected. It seems to us that, with the complete accord now reached between

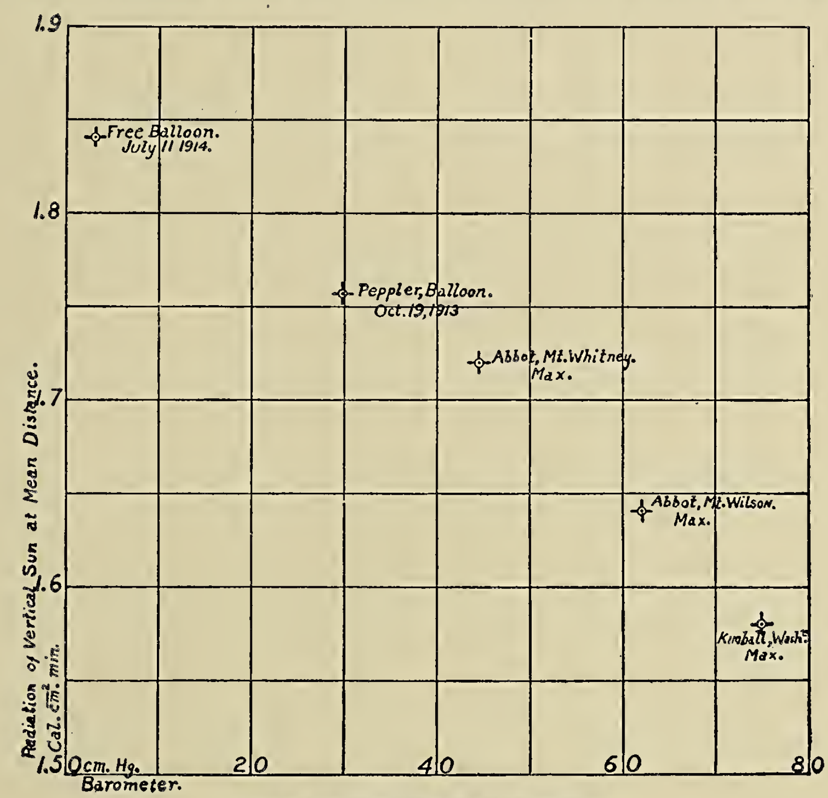

FIG. 58.—Pyrheliometry at great altitudes.

solar-constant values obtained by the spectrobolometric method of Langley, applied nearly 1,000 times in 12 years, at four stations ranging from sea level to 4,420 meters, and from the Pacific Ocean to the Sahara Desert; with air masses ranging from 1.1 to 20; with atmospheric humidity ranging from 0.6 to 22.6 mm of precipitable water; with temperatures ranging from 0° to 30° C; with sky transparency ranging from the glorious dark blue above Mount Whitney to the murky whiteness of the volcanic ash filling the sky above Bassour in 1912, it was superfluous to require additional evidence.

But new proofs are now shown in figure 58. This gives the results of an independent method of solar-constant investigation. In this method the observer, starting from sea level, measures the solar radiation at highest sun under the most favorable circumstances, and advances from one level to another, until he stands on the highest practicable mountain peak. Thence he ascends in a balloon to the highest level at which a man may live. Finally he commits his instrument to a free balloon, and launches it to record automatically the solar radiation as high as balloons may rise, and where the atmospheric pressure is reduced to the twenty-fifth part of its sea-level value. All these observations have been made. They verify the former conclusion; for they indicate a value outside the atmosphere well within the previously ascertained limits of solar variation.

Our conclusion still is that the solar constant of radiation is 1.93 calories per cm^2 per minute.

A correction.—In a letter to Mr. Abbot, Prof. F. H. Bigelow has called attention to the misrepresentation of his views in footnote 10 on page 344 of this paper. Prof. Bigelow states that he has carefully avoided using Wien's displacement law as the basis of an estimate of the solar temperature. He has used instead a consideration of the general form of the solar spectrum energy curve.

We regret having made this error. The note as it now stands seems to us to represent fairly the position of Mr. F. W. Very.[14] In order to adapt it to Prof. Bigelow's position we should require to make the following changes:

In line 3 of our note strike out the words "they determine the wave length of maximum energy, and from it."

In line 11 strike out the words "position of the maximum of energy" and substitute the words "form of the solar energy curve outside the atmosphere."

In line 17 strike out the words "position of maximum energy in its spectrum," and substitute the words "form of its energy spectrum distribution."

Strike out lines 21 to 27, inclusive.

As thus modified the main thesis of our note is as follows: Estimates of the solar constant of radiation based on estimates of the solar temperature involve: (1) The extrapolation of radiation laws thousands of degrees beyond the temperature to which they have been experimentally verified; (2) the assumption that the sun radiates like a "black body" in the face of experimental evidence that it does not; (3) dependence on the accuracy of the determination of the form of the solar-spectrum energy curve outside our atmosphere, which is a result of difficult and uncertain investigation. In short, such estimates are not determinations of the solar constant, but are merely elaborate tissues of speculation. On the other hand, we base our determination on sound and simple theory checked and verified at every point and applied over two thousand times under the most diverse circumstances, with closely agreeing results.

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[14] American Journal of Science, 4th ser., vol. 36, 609, 1913.

Appendix II.

ON PERIODICITY IN SOLAR VARIATION.*

By C. G. ABBOT.

Greatly interested by the paper of H. H. Clayton,[1] I directed Mr. Eisinger to make the necessary computations to determine by Clayton's method whether there occurred periodicities in the short interval solar variations in other years than 1913. I refer to those variations discovered by the Smithsonian Astrophysical Observatory, which often seem to run irregular courses of a week or 10 days between maxima. Clayton's method is applied as follows:

All consecutive days are written down in a column from one end to the other of the observing season of each year. Opposite these days are written in a second column the corresponding values of the "solar constant" of radiation determined on Mount Wilson. As the observations are lacking on some days, vacancies exist in this column. In a third column the same "solar-constant" values are written down, but raised one day on the scale of time. In succeeding columns up to 40 in all, the same "solar-constant" values are written down, but each column is raised one day's interval as compared with the one before. Thus as we look along from column to column the values are so arranged horizontally that we compare the "solar constant" of each day with those of one, two, and subsequent days to 40 days later. Owing to the lack of observations, not every day's value is thus compared with all the values of later days up to 40, but each day enters into some at least of these comparisons.

The observations being thus arranged, the usual computations are gone through with for obtaining coefficients of correlation between the "solar constant" of given days and those of 1 day, 2 days, and other intervals later. In selecting the groups required in correlation computations, the observations have been separated within ranges of 0.02 calorie. To avoid giving undue weight to "wild" values, such as are probably affected by progressive obscuring or clearing of the atmosphere, all values over a certain reasonable maximum or under a certain reasonable minimum are put in with the highest and lowest 0.02 calorie groups, and are regarded as falling in these ranges. Such high and low "wild" values seldom number more than 3 or 4 in a season.

As a result of these determinations of correlation coefficients, periodicities of solar variation would be exposed if they exist. For example, if the sun throughout

* Reprinted from Smithsonian Miscellaneous Collections, vol. 69, no. 6.

[1] Smithsonian Miscellaneous Collections, vol. 68, no. 3, 1917.

Fig. 59.—Periodicity in solar-constant values.

Solar-constant values. Ordinates, calories per cm² per minute; abscissæ, time of year.

Correlation values. Ordinates, correlation coefficients; abscissæ, days elapsed.

an observing season was warmer on one hemisphere than the other, we should expect that high values of the "solar constant" would tend to be succeeded by high values after about 27 days, and low values would similarly tend to be succeeded by low values about 27 days later, whereas high values would follow low values after about $13\frac{1}{2}$ days. These tendencies would express themselves in the coefficients of correlation. Positive correlation coefficients would continue for about one week, negative ones would succeed these for about two weeks more, and positive ones would follow these for the fourth and fifth week.

The results of the computations are shown graphically in the accompanying figure. On the left are plotted the "solar-constant" values as obtained on Mount Wilson, and published as far as 1912 in Volume III of the Annals of the Astrophysical Observatory. The observations of consecutive days have been connected in the plot. For the use of readers who may be interested, I give in Table 1 preliminary values of the "solar-constant" for the years 1913–1916. It is possible that in the final publication of them in Volume IV of our Annals, some changes may be made as a result of checking, but in the main they will not be altered.

On the right of figure 59 are given curves of correlation coefficients for each of the observing seasons 1908 to 1916, except 1912, when Mount Katmai volcano was in eruption, and the "solar-constant" values were less trustworthy. The curve for 1913 is taken from Clayton's paper. The others have been computed here. Two curves are given for 1915, of which the full curve represents the results of the whole year, and the dotted curve an independent computation from the results prior to September 12, which were first available. In Table 2 the correlation coefficients are printed. The probable error of individual values of these coefficients is about 0.08. For those unfamiliar with the correlation method it may be remarked that +1.00 or −1.00 are the outside limits of correlation coefficients, which both stand for perfect dependence between two variables. A value 0.00 indicates a complete absence of dependence.

(1) The first noticeable feature of the curves is their dissimilarity. No well-marked periodicity of the solar variation persists through all of the eight years of the investigation. Each season is a law unto itself.

TABLE 1.—*Solar-constant values.*

OBSERVATIONS OF THE YEAR 1913.

Date.	Solar constant.	Grade.	Date.	Solar constant.	Grade.	Date.	Solar constant.	Grade.
July 16	1.928	Vg+	Sept. 6	1.901	Vg+	Oct. 8	1.804	G+
23	1.935	Vg−	7	1.950	Vg++	9	1.806	G
24	1.911	Vg+	8	1.897	Vg++	11	1.852	E+
Aug. 3	1.928	E	9	1.936	Vg+	12	1.893	E+
4	1.916	E−	10	1.930	E−	13	....	....
5	1.958	E	11	1.912	E	14	1.861	E
6	1.913	Vg−−	14	1.907	E−	15	1.831	E
9	1.957	E−	15	1.899	Vg+?	17	1.907	E−
10	1.954	Vg−	16	1.912	Vg−	19	1.873	E+
11	1.921	Vg−	17	1.938	G+	20	1.868	E
12	1.940	Vg	18	2.000	Vg	21	1.912	E−
13	1.927	Vg	19	1.954	Vg+	22	1.893	Vg+
14	1.955	E−−	21 [1]	1.915	Vg++	23	1.871	E
15	1.922	E−	22	1.953	Vg	24	1.882	E
16	1.877	Vg+	24 [1]	1.928	E	25	1.850	E
17	1.913	E	25	1.881	Vg	26	1.871	Vg+
18	1.958	Vg+	26	1.849	E	27	1.914	G
19	1.859	Vg+	27	1.894	E	28	1.830	E−
20	1.987	Vg+	28	1.855	E+	31	1.867	Vg+
21	1.910	Vg−	29	1.882	E+	Nov. 4	1.852	E+
28	1.968	G+	30	1.907	G+	5	1.818	E+
Sept. 2	1.963	G	Oct. 1	1.869	Vg	7	1.888	Vg+
3	1.933	E+	3	1.966	Vg−	8	1.902	E
4	1.907	G−	6	1.835	Vg	9	1.918	Vg−
5	1.905	Vg	7	1.878	E			

OBSERVATIONS OF THE YEAR 1914.

Date.	Solar constant.	Grade.	Date.	Solar constant.	Grade.	Date.	Solar constant.	Grade.
June 12	1.977	G+	June 20	1.949	Vg−	Aug. 11	1.987	E+
13	1.943	E−	21	1.968	E	12	1.962	E−
14	1.944	E−	22	1.950	E+	14	1.952	Vg+
15	1.979	E+	23	2.004	Vg+	17	1.923	E−
16	1.938	E	July 26	1.934	Vg++	18	1.937	Vg
19	1.916	Vg	27 [1]	1.948	E−	19	1.935	E−
20	1.954	E−−	28	1.968	Vg+	20	1.969	G
21	1.918	E	29	1.921	Vg−−	21	1.947	E+
22	1.975	E−	30	2.031	Disturbed weather. Sky streaked with cirri.	22	1.942	E
23	1.943	E+	Aug. 1	2.062		23	1.975	E+
24	1.936	Vg−−	2	1.966		24	1.928	G−
25	1.958	Vg	5 [1]	2.099		26	1.934	E
26	1.966	E				27	1.951	Vg+
30	1.981	Vg+	7	1.989	Vg	28	1.940	E
1	1.973	E				29	1.779	Disturbed weather. Sky streaked with cirri.
2	1.947	E−	8	1.945	Exceptional humidity.			
17	1.932	E				30	2.057	
18	1.901	E	9	1.987	E−	31	1.987	
19	1.951	Vg+	10	1.949	E			

[1] Afternoon observations.

TABLE 1.—*Solar-constant values*—Continued.

OBSERVATIONS OF THE YEAR 1914—Continued.

Date.	Solar constant.	Grade.	Date.	Solar constant.	Grade.	Date.	Solar constant.	Grade.
Sept. 1	1.915	E	Sept. 14	1.954	E	Oct. 4	1.939	E (?)
2	1.948	E	15	1.965	E−	9	1.947	E
3	1.942	E	16	1.951	E+	10	1.961	G
4	1.949	E+				11	1.940	E
6	1.921	E+	19	1.921	Exceptional humidity.	12	1.951	Vg+
7	1.944	G+				13	1.946	E+
8	1.958	E−	20	1.936	E	14	1.933	Vg
9	1.932	Vg	21	1.960	E	15	1.973	Vg+
10	1.954	E−	22	1.915	Vg+	16	1.946	Vg
11	1.946	Vg	23	1.985	E	18	1.960	E−
12	1.936	Vg	28	1.941	E+	19	1.949	E
13	1.922	E+	Oct. 2	1.956	G−	20	1.955	E+

OBSERVATIONS OF THE YEAR 1915.

Date.	Solar constant.	Grade.	Date.	Solar constant.	Grade.	Date.	Solar constant.	Grade.
June 8	1.927	E	July 30	1.920	Vg+	Sept. 6	1.987	E+
10	1.944	E	31	1.905	Vg	7	1.982	E
13	1.909	E−	Aug. 1	1.954	Vg+	12	1.942	Vg?
16	1.899	G	2	1.914	E+	17	1.990	E−
18	1.969	Vg	3	1.946	E−	18	2.020	E
19	1.920	G+	6	1.942	Vg+	19	1.956	E−
22	1.900	E−	7	1.950	E+	20	1.971	E
24	2.010	E−	8	1.975	E	22	1.969	Vg
25	1.999	E	9	1.962	E+	23	1.949	E−
26	1.935	E	10	1.945	E−	27	1.920	Vg
27	1.949	E−	11	1.993	Vg	28	1.934	Vg+
28	1.980	E−	12	1.950	Vg+	Oct. 1	1.977	E
July 3	1.910	E−	13	1.950	E+	2	1.898	Vg
4	1.949	E−	14	1.975	Vg+	4	1.974	Vg
5	1.930	E	15	1.964	Vg	5	1.956	Vg−
6	1.977	E	16	1.966	Vg	6	1.943	Vg
7	1.960	E+	17	1.944	E+	7	1.932	Vg+
8	1.948	E	18	1.940	E	8	2.052	G+
9	1.931	E	19	1.931	Vg	9	1.967	Vg+
10	1.925	E	20	1.918	G	11	1.944	P
11	1.944	E	21	1.931	Vg+	12	1.945	Vg+
12	1.945	Vg	22	1.946	E+	13	1.951	E−
13	1.957	G	23	2.000	Vg−	14	1.920	Vg+
14	1.949	Vg	24	1.956	E−	15	1.893	Vg−
15	1.975	E	25	1.960	G+	16	1.944	Vg+
16	1.974	E	27	1.893	Vg−	17	1.952	E−
17	1.980	E	28	1.976	Vg−	18	1.952	E−
18	1.958	Vg	29	1.915	Vg+	19	1.944	Vg
26	1.948	E−	31	1.887	Vg+	20	1.938	Vg−
27	1.942	E	Sept. 3	1.969	Vg+	21	1.950	E+
28	1.935	Vg+	4	1.946	Vg−	22	1.931	Vg
29	1.933	E	5	1.942	Vg			

Table 1.—*Solar-constant values*—Continued.

OBSERVATIONS OF THE YEAR 1916.

Date.	Solar constant.	Grade.	Date.	Solar constant.	Grade.	Date.	Solar constant.	Grade.
June 17	1.941	Vg+	July 25	1.944	E−	Sept. 6	1.921	Vg−
19	1.940	E−	28	1.945	E−	7	1.940	G
20	1.949	Vg	29	1.932	E−	8	1.957	Vg+
22	1.947	E−	30	1.953	E−	9	1.906	Vg
23	1.989	Vg+	31	1.940	Vg−	10	1.899	E−
24	1.966	E−	Aug. 10	2.010	G+	11	1.955	E−
25	1.938	Vg	11	1.942	G	12	1.937	Vg+
26	1.948	Vg−	12	1.879	Vg	13	1.923	E
30	1.914	Vg−	13	1.962	Vg	14	1.923	E
July 1	1.953	G+	14	1.987	Vg−	15	2.025	G+?
2	1.929	G	15	1.942	E−	16	1.968	Vg
3	1.947	Vg−	16	1.935	E+	17	1.934	G
4	1.954	Vg+	17	2.011	Vg	18	2.033	Vg
5	1.945	E−	18	1.920	Vg−	23	1.936	Vg
6	1.951	Vg	19	1.931	Vg	27	1.933	Vg+
7	1.942	Vg+	20	1.955	Vg	28	1.929	G?
8	1.942	E−	21	1.976	G	Oct. 5	1.897	P
9	1.958	Vg+	22	1.944	Vg	8	1.860	E−
10	1.876	G+	25	1.940	P	12	1.962	Vg−
11	1.914	Vg−	27	1.936	G−	14	1.955	E
12	1.925	G+	28	2.011	G	15	1.923	E
15	1.913	Vg	29	1.911	G+	16	1.934	Vg−
16	2.016	G	30	1.937	G	17	1.950	Vg+
17	1.940	E−	31	1.948	E−	18	1.934	E−
18	1.931	Vg	Sept. 1	1.929	Vg+	19	1.954	E−
19	1.964	E+	2	1.913	Vg−	20	1.969	E
22	1.952	Vg−	3	1.911	P	22	1.962	G−
23	1.992	Vg−	4	1.970	Vg?			
24	2.011	Vg−	5	1.936	Vg			

(2) In the second place we find positive correlations on the first day in all years except 1916. The lack of it in 1916 is explainable, as we shall see. Hence the supposedly solar variations are surely not due to mere accidental errors of observation, for this result shows that during several days in a group the solar constant values are apt to be affected in the same direction. This is not a certain proof that the variations are solar. The same thing would very likely be found if they were due to atmospheric causes.

However, the variability of the sun is now indicated[2] by (*a*) Mount Wilson observations of the solar constant, (*b*) comparison of Mount Wilson and Bassour observations, (*c*) comparison of Mount Wilson and Arequipa observations, (*d*) comparison of Mount Wilson and magnetic observations, (*e*) comparison of Mount Wilson solar-constant work with Mount Wilson solar-contrast work. The cumulative effect of this evidence is overwhelming.

[2] See Annals of the Smithsonian Astrophysical Observatory, III; Smithsonian Miscellaneous Collections, 65, nos. 4 and 9, and 66, no. 5; Terrestrial Magnetism and Atmospheric Electricity, 20, 143, 1915.

TABLE 2.—*Correlation solar-constant coefficients.*

Days later.	Years.								Mean.	
	1908	1909	1910	1911	1913	1914	1915	1916	1908, 1911, 1913.	1909, 1910, 1914.
1	+0.211	+0.508	+0.093	+0.137	+0.47	+0.084	+0.262	−0.008	+0.273	+0.228
2	+ .152	+ .254	+ .244	− .045	+ .05	+ .458	+ .190	− .126	+ .052	+ .319
3	+ .085	+ .258	+ .103	.000	.00	+ .038	+ .128	+ .323	+ .028	+ .133
4	+ .014	+ .115	+ .102	+ .144	− .15	+ .178	+ .010	− .020	+ .003	+ .132
5	+ .069	+ .002	+ .367	+ .142	− .01	+ .031	− .141	− .222	+ .067	+ .133
6	+ .087	+ .080	− .021	+ .338	− .01	+ .035	− .074	− .243	+ .138	+ .031
7	+ .091	+ .194	+ .124	+ .134	− .17	+ .087	+ .006	+ .280	+ .018	+ .135
8	+ .095	+ .153	− .048	+ .231	− .05	+ .404	− .229	− .026	+ .092	+ .170
9	+ .050	+ .184	+ .083	+ .073	− .18	+ .078	− .170	− .261	− .019	+ .115
10	− .127	+ .223	− .103	− .272	− .13	+ .116	− .129	− .027	− .176	+ .079
11	− .201	− .033	− .114	− .035	− .01	+ .058	− .122	+ .354	− .082	− .030
12	− .174	+ .061	− .131	+ .057	+ .27	− .099	− .249	− .215	+ .051	− .056
13	+ .045	+ .083	+ .033	+ .057	+ .02	+ .055	− .145	− .257	+ .041	+ .057
14	+ .103	+ .131	− .041	+ .138	− .22	− .219	− .116	+ .053	+ .007	+ .043
15	− .028	+ .053	− .052	+ .175	+ .13	+ .148	− .247	− .012	+ .092	+ .050
16	+ .005	− .001	− .178	+ .062	− .06	− .030	− .339	− .289	+ .002	− .070
17	+ .008	− .162	− .085	+ .170	− .02	− .176	− .173	− .204	+ .053	− .141
18	+ .119	− .181	+ .056	− .060	+ .04	− .176	− .097	+ .374	+ .033	− .100
19	+ .081	− .196	− .258	− .051	− .13	+ .058	+ .069	− .265	− .033	− .132
20	+ .076	− .122	− .071	+ .065	+ .18	− .085	+ .124	− .184	+ .107	− .093
21	+ .046	− .105	− .173	+ .362	+ .01	− .024	+ .209	+ .270	+ .139	− .101
22	+ .126	+ .035	+ .050	+ .033	− .04	+ .028	+ .257	+ .165	+ .040	+ .038
23	+ .036	+ .068	− .159	− .017	+ .16	+ .024	+ .094	− .216	+ .060	− .022
24	+ .075	− .147	+ .027	− .051	+ .20	+ .184	+ .013	− .184	+ .075	+ .021
25	+ .047	− .084	− .054	− .016	− .22	− .269	+ .128	+ .456	− .063	− .136
26	+ .039	− .092	+ .099	− .063	+ .09	+ .002	+ .169	+ .049	+ .022	+ .003
27	− .154	− .100	+ .027	+ .002	+ .02	− .110	+ .443	− .276	− .044	− .061
28	− .187	− .079	+ .033	− .106	+ .08	− .013	+ .268	+ .088	− .071	− .020
29	− .132	+ .152	+ .084	+ .132	+ .03	+ .055	+ .369	+ .334	+ .010	+ .097
30	− .200	+ .030	+ .084	− .012	+ .01	+ .080	+ .317	− .225	− .067	+ .065
31	− .146	− .157	+ .359	− .240	+ .02	+ .114	+ .151	− .196	− .122	+ .105
32	− .156	− .119	− .056	− .058	− .18	+ .080	− .002	+ .436	− .131	− .032
33	− .153	+ .050	+ .067	+ .190	+ .02	− .172	− .206	+ .001	+ .019	− .018
34	− .169	− .258	+ .067	+ .126	− .12	− .081	− .223	− .134	− .054	− .091
35	− .162	− .181	− .227	− .079	+ .28	+ .006	− .431	+ .098	+ .013	− .134
36	− .153	− .035	+ .123	− .002	+ .01	− .133	− .375	+ .344	− .048	− .015
37	+ .054	+ .114	+ .057	+ .098	....	− .014	− .255	− .097	+ .076	+ .052
38	− .180	+ .169	+ .195	+ .174	....	− .006	− .189	− .203	− .003	+ .119
39	− .148	+ .011	+ .011	− .326	....	− .121	− .126	+ .189	− .237	− .033
40	− .037	+ .047	− .094	+ .052	....	+ .070	− .343	− .036	+ .008	+ .008

(3) We may next note the striking result for the year 1915. Two curves of correlation are given for 1915, of which the full line is computed from all observations of that year, the dotted curve from those prior to September 12. Both curves show strongly a periodicity of about 27 days, no doubt associated with the solar

rotation. There was evidently during this season a tendency toward a hot and cold side of the sun, which persisted during several solar rotations but diminished at the latter end of the season. Such a result is evidently a new proof that the variations we find are truly solar, for they have a well-known solar period in 1915.

(4) Not less extraordinary is the result for 1916. The 27-day periodicity seems to be no longer present, but $11\frac{1}{3}$ full periods, as regular as the time intervals of 24 hours between observations permit, occur in 40 days. This periodicity is then approximately 3.5 days. It is unique among the whole series of years. If the range of the correlation factors was smaller I would regard it as surely due to accidental error. But the range averages more than 50 per cent from crest to trough in correlation factors whose probable error is only about 8 per cent. It is really a most extraordinary result.

(5) The years 1909, 1910, and 1914 show a similarity in the march of correlation factors. From strongly marked positive values during the first week the coefficients fall to minimum negative values after about 18 days, and then, on the whole, tend to approach zero toward the end of our 40-day period of investigation. In the seventh curve of the figure, corresponding with the last column of Table 2, I give the mean of correlation factors from all three years. This curve brings out in addition to the tendency just noted, a fairly well marked indication of a periodicity of $7\frac{1}{2}$ days.

(6) The results for the remaining years 1908, 1911, and 1913 differ from all the others and from each other, but on the whole if they stood alone would give less ground for a belief in the periodicity of solar variations than the group of three years we have been discussing, and much less than the years 1915 and 1916. In the sixth curve, corresponding to column 10 of Table 2, I give the mean values for these three years.

(7) To sum up the investigation, we find in 1915 a well-marked hot and cold side of the sun persisting through several solar rotations. This occurred in a year near sun-spot maximum. The years 1909, 1910, 1914, either of moderating or of slowly increasing solar activity, show tendencies toward periodicities of solar variation, not very marked, but somewhat in common over the three seasons. The years 1908, 1911, and 1913 yield little of interest. The year 1916 yields a unique and extraordinary result. No definite periodicity in solar variations of short interval persists year after year.

Appendix III.

THE REFLECTING POWER OF CLOUDS.*

By L. B. ALDRICH.

INTRODUCTION.

In the spring of 1918, the War Department established an observation balloon school at Arcadia, California. On clear days the balloons of this school are in full view from the Smithsonian observing station on Mount Wilson. The valley to the south and west of Mount Wilson is often filled in the early morning with dense fog, and from the mountain top one looks down upon a surface of white, billowy clouds remarkably level and unbroken as a whole. Usually after several hours the fog is dissipated, but on rare occasions it lasts until noon or later. From this combination of circumstances it appeared evident that one of these observation balloons sent up through such a fog sea offered an unusual opportunity for determining the reflecting power of a cloud surface practically filling a hemisphere of solid angle. The top of the mountain, to be sure, would cut off a portion of the horizon, but being in the quarter opposite the sun, several miles distant and with intervening haze itself supplying nearly as much radiation as the small solid angle of cloud it took the place of, no correction would be needed to allow for the presence of the mountain. Accordingly Dr. Abbot obtained from the director of military aeronautics, Gen. Kenly, permission to use a balloon and detail of officers and men for cloud reflection work on the first favorable day. Preliminary arrangements were made with the commanding officer at Arcadia, and a favorable day awaited.

On September 16, 1918, a very heavy fog filled the valley, persisting all day and its top level almost reaching the summit of Mount Wilson. Prospects seemed excellent for a similar heavy fog at a lower level on September 17, and final arrangements for the experiments were made. The sky conditions of September 17 more than fulfilled expectations. A dense, homogeneous fog, usually level and even on top, filled the valley. Its upper surface was about 800 meters (2,600 feet) from the ground. It was 500 meters (1,600 feet) thick at the start and 180 meters (600 feet) thick at the close of the work.[1]

* Reprinted from Smithsonian Miscellaneous Collections, vol. 69, no. 10.

[1] In passing up and down through the layer of fog the observer reported as follows:

Pacific standard time	6 hr. 55 min.	9 hr. 00 min.	10 hr. 00 min.	10 hr. 55 min.
Level of bottom (feet)	1,000	1,800	....	2,000
Level of top (feet)	2,600	2,600	2,600	2,600

Such a thinning of the fog from the bottom without much change in its upper level seems curious and is probably unusual.

The sky above was cloudless and very clear. Under these conditions the following experiments were made.

OBJECT AND METHOD OF THE EXPERIMENTS.

It was desired to determine what proportion of the rays of the sun, including sun rays scattered by the sky, is reflected upward from a level layer of cloud of indefinite extent. For this purpose a pyranometer [2] having a glass hemispherical cover was to be exposed in one series of experiments in its inverted position to measure the rays coming up from fog in the hemisphere below, and on a similar day in the usual position to measure the rays from the sun and sky in the hemisphere above. The glass cover served as a screen to sift out for observation rays lying between 0.3 micron and 3 microns in wave length. These rays comprise practically all rays of relatively appreciable intensity in the solar spectrum. The glass excludes rays of more than 3 microns in wave length such as the earth, the clouds, and the atmosphere emit by virtue of their proper temperatures. In order to determine whether the reflecting power of a wide sheet of cloud differs much with the angle of incidence of the rays, it was desirable to begin the experiments at low sun and continue them till the sun reached high altitude above the horizon. Experiments reported in Volume II of the Annals of the Smithsonian Astrophysical Observatory [3] of course show that the reflection varies in azimuth and nadir distance greatly with the angle of incidence. But it was not shown certainly whether the total intensity of the reflected rays summed up over all azimuths and nadir distances within a hemisphere would change much with the angle of incidence of the rays upon the cloud layer.

ARRANGEMENTS.

Pyranometer A. P. O. No. 5, modified for use in the eclipse expedition of June 8, 1918,[4] was somewhat further modified for this work. It was proposed to suspend the pyranometer, inverted, below the basket of the balloon, thus exposing the pyranometer strip to the radiation from a practically infinite cloud surface. The sunshade was removed and the glass hemisphere securely fastened in place with shellac. The pyranometer was suspended about one-half meter below the bottom of the balloon basket, and a flexible shaft, operating the shutter through miter gears, extended to within easy reach of the officer in the basket. For stability the galvanometer was necessarily mounted on the ground and connected to the pyranometer through a reel of special telephone wire. (Insulated piano wire was employed such as is used in ordinary balloon work for telephone communication with the ascending officer. This introduced probably over 1,000 ohms

[2] See Smithsonian Miscellaneous Collections, vol. 66, nos. 7 and 11, 1916.

[3] For further discussion of the theory of the method of observing see the figure and explanation given in Addenda to Annals Vol. II, entitled, "Note on Reflecting Power of Clouds."

[4] See Smithsonian Miscellaneous Collections, vol. 69, no. 9.

resistance into the galvanometer circuit, but the pyranometer was sufficiently sensitive to give deflections ranging from 1.50 to 4 cms and could be read to 0.01 cm.) The galvanometer, ammeter, and accessories were the same as used on the eclipse expedition of June, 1918.[4]

Observation balloon No. 7, with its complement of officers and men, was assigned to aid in the work. The writer wishes to express his appreciation for their assistance, and particularly for the interest and efficient help of Lieut. E. W. Raeder, the ascending officer. Lieut. Raeder reported the sky conditions and manipulated the pyranometer shutter from the balloon basket, being in constant telephone communication with the ground through a second reel of telephone wire. His great zeal and gallantry are shown by the fact that, being alone in the basket, he tied his ankle by a bit of rope to the balloon and hung head downward for about 5 minutes to fix a defect in the exposing apparatus which developed near the end of the experiments, then climbed back and continued the observations.

OBSERVATIONS.

The observations of cloud, sun, and sky, and of electric current for calibration of the pyranometer, are given in Table 1. As the balloon was brought to earth between observations of groups 7 and 8 (see table) three current calibrations [5] were made—just before the first ascension, between the first and second, and after the second ascension. The galvanometer circuit was unchanged throughout the observations, so that the calibrations were made under the same conditions as the cloud observations, save that the balloon was near the ground for the former and above the fog for the latter.

TABLE 1.—*Reflecting power of clouds.*

Group No.	Hour angle of sun (east).	Air mass of sun (sec. Z).	Brightness of sky alone on horizontal surface.	Sun alone per cm² normal to beam.	Sky and sun per cm² of horizontal surface.	Calories per cm² reflected from cloud.	Altitude of instrument above cloud surface.	Wind velocity at balloon basket (meters per second).	Number of individual determinations.	Current calibration values of $\frac{C^2}{Dc}$.	Mean deflections of galvanometer (cm).	Per cent reflected from cloud surface.	Probable error.	Maximum range of galvanometer zero drift (cm).	Estimated grade based on zero drift.
	h. m.		*Calories.*	*Calories.*	*Calories.*		*Meters.*						*Per ct.*		
1	4 29	2.84	0.064	1.250	0.504	0.401	30	0	10	0.01085	1.532	79.6	1.2	0.16	E.
2	15	2.47	.070	1.303	.598	.460	120	4	10	.01089	1.752	76.9	.5	.54	V. g.
3	01	2.26	.073	1.337	.665	.530	210	9	11	.01093	2.014	79.7	1.4	2.56	P.
4	3 48	2.07	.077	1.367	.737	.567	120	3	10	.01097	2.144	77.0	.8	.57	V. g.
5	35	1.92	.080	1.390	.804	.615	25	0	11	.01100	2.317	76.5	.7	.22	E.
6	12	1.71	.083	1.424	.916	.824	25	0	11	.01104	3.098	90.0	1.5	1.25	F.
7	2 56	1.59	.086	1.442	.994	.868	105	2	10	.01108	3.251	87.4	.8	.67	G.
8	1 34	1.26	.092	1.493	1.278	1.019	60	5	9	.01114	3.787	79.8	2.2	1.19	F.
9	18	1.24	.093	1.497	1.300	1.145	60	5	10	.01115	4.265	88.1	3.0	2.80	V. p.
10	09	1.22	.094	1.500	1.324	1.051	50	3.5	6	.01118	3.897	79.4	.8	.42	V. g.
11	0 59	1.20	.094	1.503	1.346	.945	50	3.5	8	.01118	3.514	70.2	1.1	.81	G.

Mean of all=80.4 per cent. Mean of first five=77.9 per cent. Mean of all with probable error 1.2 per cent or less (7 values)=78.1 per cent. Adopted best value=78 per cent ± 1.1 per cent.

[5] The first-swing method was used. See Smithsonian Miscellaneous Collections, vol. 66, no. 11, p. 8.

Column 5 in the table (total solar radiation per cm^2 normal to the beam) was obtained as follows: On the morning of September 16 the usual solar constant observations, which include pyrheliometer measurements of the total solar radiation on normal surface, were made on Mount Wilson. Then on September 17, simultaneously with the cloud reflection observations, Mr. H. Benioff of the Mount Wilson Solar Observatory staff, very kindly made pyrheliometer readings on Mount Wilson with pyrheliometers IV and VII. He made eight determinations, the mean of which gave for an air mass 1.5 the value 1.46 calories, total solar radiation received per square centimeter of normal surface. The plotted values of September 16 give for the same air mass the practically identical value, 1.452 calories. Furthermore, the solar constants determined at the recently established Smithsonian station in Chile are:

September 16, 1918	1. 960
September 17, 1918	1. 951

As far as visual observations of the sky could indicate the two days were identical. Thus, since the two days show nearly identical solar constant values and nearly identical pyrheliometer values at a given air mass, it is to be assumed that the pyrheliometer values for the whole range of air masses would have been nearly identical. Values of column 5 are therefore taken from the pyrheliometer curve of September 16.

Column 4, the sky brightness, was not so easily obtained. Unfortunately, owing both to delay in the return of instruments and to an unprecedented amount of cloudy weather, sky brightness values on a day with sky conditions similar to September 17 were not available.[6] The pyranometer data of previous years was examined and two days chosen, one of greater haziness and one of greater clearness than September 17, as follows:

Place.	Date.	Sky brightness at air mass.		Kind of sky.
		1.2	2.8	
		Calories.	*Calories.*	
Mount Wilson, California	Aug. 7, 1916, (a. m.).	0. 105	0. 065	Very hazy. Pyrheliometer 5 per cent lower than Sept. 17, 1918.
Hump Mountain, North Carolina.	Nov. 17, 1917 (a. m.).	. 085	. 061	Very clear. Pyrheliometer values not obtained, but on neighboring days were several per cent above Mount Wilson values of Sept. 17, 1918.

A mean between the values of sky brightness for these two days was adopted as the sky brightness for September 17, 1918. It is certain that on the first of these days the sky was brighter than on September 17, and on the second it was

[6] It will be possible to obtain such values at some future time, however.

less bright than on September 17. If we were to adopt the values of either of these two days, the resulting values of total sky and sun brightness of September 17 would not be altered by so much as 1 per cent from those given in the table.

Comparisons of the pyranometer with pyrheliometer IV on the sun alone were made before this work,[7] and again after the work on October 8 and October 9. A mean of 10 values on these last two days gave a constant 2½ per cent higher than the earlier comparisons. Taking a mean of all comparisons, the constant of the pyranometer was regarded as 24.1 instead of 23.8 as used for the eclipse reductions. The computed values originally obtained from measurements of dimensions, electrical resistances and assumed absorbing power of the pyranometer strips is 25.9. That recent observed values are so much lower is doubtless due to rough usage of the blackened surface necessary in fastening in new thermocouples.

It is to be noted that a very considerable irregular galvanometer drift was present throughout the cloud observations. This seemed due mainly to the changing air currents as the balloon basket swung in the wind. Table 1 shows that in general the higher the wind velocity, the greater the range of zero drift. Inadequate protection of the galvanometer from vibrations caused by passing trains and auto trucks also contributed to the drift. However, since each individual determination required but five seconds and in each group the mean of a number is used, the error from irregular drift is minimized. The writer is inclined to place more weight in the observations of the first half of the morning, for the fog then was thicker and its top surface more level. As the sun rose higher there was not only more boiling of the fog surface but the increased temperature differences tended to increase possible thermoelectric disturbances.

RESULTS.

The mean value is 78 per cent. No evidence of a change of reflecting power with a change in solar altitude is evident for the range of air masses in Table 1. This is of importance in deducing a value of the albedo of the earth from these results, for it tends to show not only that fog layers near the boundaries of the earth's surface differ little in reflecting power from those directly under the sun, but also that rough clouds do not differ very much from smooth ones in reflecting power. This latter point of course should not be urged too far, for it is obvious that clouds with very deep holes and furrows must reflect less than smooth ones.

Referring to the discussion of cloud reflecting power in Volume II, Annals of the Smithsonian Astrophysical Observatory, page 145, we find that using 65 per cent as the reflecting power of a cloud surface a value of 33.7 per cent is obtained as the total amount of the incoming solar radiation over the whole earth reflected to space by clouds. Substituting 78 per cent for 65 per cent this value becomes

[7] See Report of Eclipse Expedition, Smithsonian Miscellaneous Collections, vol. 69, no. 9, p. 6.

40.4 per cent. It seems probable that the low cloud reflection value of the early Mount Wilson work (65 per cent for cloud reflecting power) can be attributed largely to the uncertainty of the extrapolations necessary, since the observations were limited to a small range of nadir distance. Moreover, the contribution from the very bright area near the angle of specular reflection was perhaps minimized.

Following the method of pages 162 and 163 (Annals, Vol. II), a new value of the albedo of the earth is derived. Using 78 per cent as the cloud reflecting power, the albedo of the earth (as defined by Bond, see article by Russell, Astrophysical

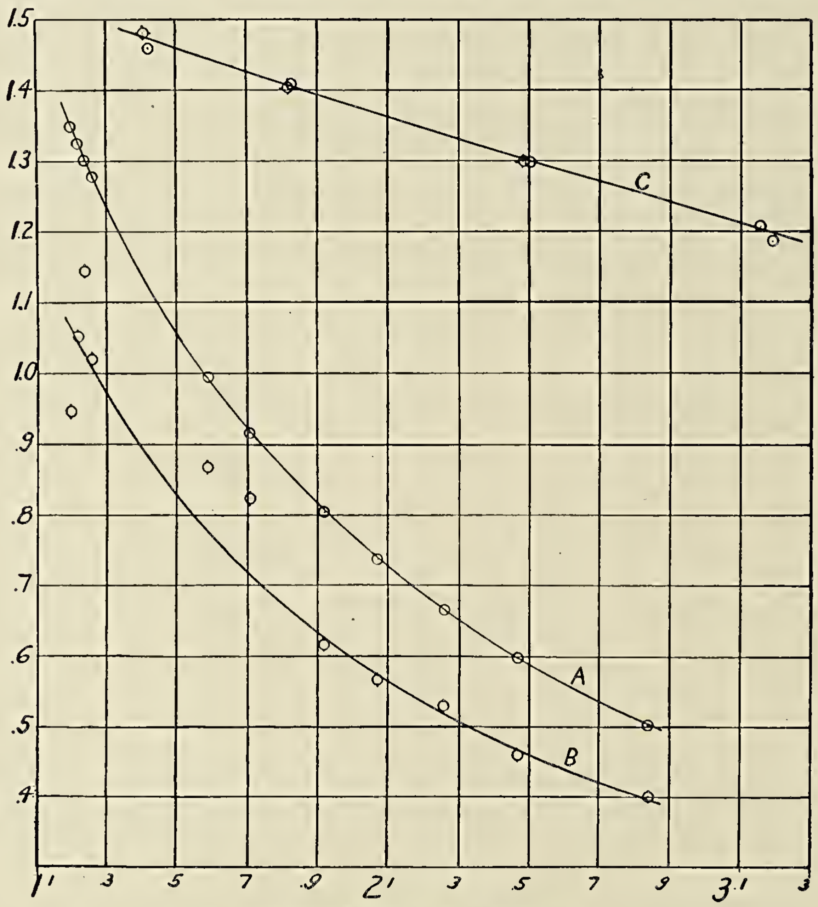

Fig. 60.—Reflecting power of clouds

Abscissæ=air masses. Ordinates=calories.
Curve A=total sky and sun per cm² of horizontal surface.
Curve B=calories reflected from cloud per cm² of horizontal surface.
Curve C=pyrheliometry of September 16, 1918. Total calories from sun alone per cm² normal to beam.

Journal, 43, p. 175) becomes 43 per cent. Russell (Astrophysical Journal, 43, p. 190) derives for it a value of 45 per cent from a consideration of Very's visual observations on Venus and the moon.

It will be clear that the method here adopted to get the cloud reflecting power (i. e., taking the ratio of the total radiation received by the pyranometer per square centimeter of horizontal surface from the cloud, to the total radiation received from sky and sun by a square centimeter of horizontal cloud surface) may give different results from measurements by visual or photographic methods as employed in photometry. Although even in the present work part of the solar rays is missing, owing to water vapor absorption, the results are more clearly applicable to considerations of the earth's temperature than photometric results would be. Still it is probable that the difference is small.

The planet Venus, according to Russell's discussion of Müller's observations, has a Bond albedo of 59 per cent for visual rays. Because of its high reflecting power and the absence of telescopic markings Venus is usually regarded as altogether cloudy. If this is the case, unless the clouds are very deeply broken up by pits and billows an albedo for total radiation of 78 per cent (or even a little more considering the specular reflection near the edges of the sunlit surface) would be expected. Young notes that the limb of the planet is always much brighter than the central parts. This may indicate that the clouds while general are not thick enough to give full cloud reflection except for rays received obliquely.

SUMMARY.

A pyranometer suspended below the basket of an Army observation balloon was used to measure the reflecting power of a level cloud surface practically filling a hemisphere of solid angle. Over 100 determinations were made. The solar air masses ranged from 2.8 to 1.2, and the sky above was cloudless and very clear. A mean value of 78 per cent is obtained. No change of total reflection depending on solar zenith distance is apparent within a range of zenith distance from 33° to 69°. A value of 43 per cent for the albedo of the earth is obtained by revision of the earlier value of Abbot and Fowle (Annals, Vol. II, p. 162) which depended on a lower value of cloud reflection based on observations over but a small part of a hemisphere.

Appendix IV.

LIST OF PAPERS PUBLISHED BY MEMBERS OF THE OBSERVATORY STAFF.

[Continued from page 231 of Volume III of these Annals.]

Abbot, C. G. Report of the Astrophysical Observatory of the Smithsonian Institution for the year ending June 30, 1913.

Abbot, C. G. Do volcanic explosions affect our climate? National Geographic Magazine, February, 1913.

Abbot, C. G., Fowle, F. E., and Aldrich, L. B. The variation of the sun. The Astrophysical Journal, 38, p. 181, 1913.

Abbot, C. G., Fowle, F. E., and Aldrich, L. B. Die Solarkonstante und ihre Schwankungen. Meteorologische Zeitschrift, p. 257, 1913.

Abbot, C. G., Fowle, F. E., and Aldrich, L. B. The variation of the sun. Memorie della Societá degli Spettroscopisti Italiani, 2, 81, 1913.

Abbot, C. G., Fowle, F. E., and Aldrich, L. B. La variabilité du soleil. Bulletin astronomique, 30, p. 393, 1913.

Abbot, C. G., Fowle, F. E., and Aldrich, L. B. The variation of the sun. Astronomische Nachrichten, 194, p. 432, 1913.

Fowle, F. E. The nonselective transmissibility of radiation through dry and moist air. Astrophysical Journal, 38, p. 393, 1913.

Abbot, C. G. Report of the Astrophysical Observatory for the year ending June 30, 1914.

Abbot, C. G. Recent progress in Astrophysics. Smithsonian Report for 1913, p. 175.

Abbot, C. G. The solar constant of radiation. Retiring presidential address before the Philosophical Society of Washington. Science, 39, p. 335, 1914.

Abbot, C. G. The solar constant of radiation. Journal of the Washington Academy of Sciences, 4, p. 89, 1914.

Abbot, C. G. The radiation of the sun. Journal of the Franklin Institute, p. 641, June, 1914.

Abbot, C. G. The direct and scattered radiation of the sun and stars. The Astronomical Journal, 28, p. 129, 1914.

Abbot, C. G. The variable sun. Harper's Magazine, July, 1914.

Abbot, C. G. The radiation of the sun. Smithsonian Report for 1914, p. 137.

Fowle, F. E. Smithsonian Physical Tables. Sixth revised edition. Smithsonian Miscellaneous Collections, vol. 63, no. 6, 1914.

Fowle, F. E. Avogadro's constant and atmospheric transparency. Astrophysical Journal, 40, p. 435, 1914.

Fowle, F. E. Die Durchlässigkeit der Atmosphäre für Strahlung. Meteorologische Zeitschrift, p. 270, 1914.

Fowle, F. E. Atmospheric transparency for radiation. Monthly Weather Review, p. 1, 1914.

Abbot, C. G. Report of the Astrophysical Observatory of the Smithsonian Institution for the year ending June 30, 1915.

Abbot, C. G., Fowle, F. E., and Aldrich, L. B. New evidence on the intensity of solar radiation outside the atmosphere. Smithsonian Miscellaneous Collections, vol. 65, no. 4, 1915.

Fowle, F. E. The transparency of aqueous vapor. Astrophysical Journal, 42, p. 394, 1915.

Abbot, C. G. Report of the Astrophysical Observatory of the Smithsonian Institution for the year ending June 30, 1916.

Abbot, C. G. Arequipa pyrheliometry, 1916. Smithsonian Miscellaneous Collections, vol. 65, no. 9, 1916.

Abbot, C. G., Fowle, F. E., and Aldrich, L. B. On the distribution of radiation over the sun's disk and new evidences of the solar variability. Smithsonian Miscellaneous Collections, vol. 66, no. 5, 1916.

Abbot, C. G., and Aldrich, L. B. The pyranometer—an instrument for measuring sky radiation. Smithsonian Miscellaneous Collections, vol. 66, no. 7, 1916.

Abbot, C. G., and Aldrich, L. B. On the use of the pyranometer. Smithsonian Miscellaneous Collections, vol. 66, no. 11, 1916.

Abbot, C. G. News from the stars. Smithsonian Report for 1916, p. 157.

Abbot, C. G., Fowle, F. E., and Aldrich, L. B. Intensität der Sonnenstrahlung ausserhalb der Atmosphäre. Meteorologische Zeitschrift, p. 49, 1916.

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Fowle, F. E. Smithsonian Physical Tables. Second reprint of the sixth revised edition with further changes. Smithsonian Miscellaneous Collections, vol. 63, no. 6, 1916.

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Abbot, C. G. On DeLury's hypothesis as to the effect of haze on measures of the solar rotation. Astrophysical Journal, 45, p. 65, 1917.

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Abbot, C. G. Pyrheliometry and solar radiation. Science, 47, p. 609, 1918.

Abbot, C. G. Terrestrial temperature and atmospheric absorption. Proceedings of the National Academy of Sciences, 4, p. 104, 1918.

Abbot, C. G. On periodicity in solar variation. Smithsonian Miscellaneous Collections, vol. 69, no. 6, 1918.

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Abbot, C. G. The discovery of helium and what came of it. Smithsonian Report for 1918, p. 121.

Abbot, C. G. Introductory note to Dr. P. W. Bridgman's "The properties of matter when under high pressure." Smithsonian Report for 1918, p. 185.

Abbot, C. G. Report of the Astrophysical Observatory of the Smithsonian Institution for the year ending June 30, 1919.

Abbot, C. G. The solar-constant station at Calama, Chile. Monthly Weather Review, 47, p. 1, 1919.

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Abbot, C. G. How the sun makes plants grow. Youth's Companion, Sept. 11, 1919.

Aldrich, L. B. The Smithsonian eclipse expedition of June 8, 1918. Smithsonian Miscellaneous Collections, vol. 69, no. 9, 1919.

Aldrich, L. B. The reflecting power of clouds. Smithsonian Miscellaneous Collections, vol. 69, no. 10, 1919.

Abbot, C. G., and Moore, A. F. Observations of the total solar eclipse of May 29, 1919. Smithsonian Miscellaneous Collections, vol. 71, no. 5, 1920.

Abbot, C. G. Report of the Astrophysical Observatory of the Smithsonian Institution for the year ending June 30, 1920.

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Abbot, C. G. Measurements of the solar constant of radiation at Calama, Chile:

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May, 1919	July, 1919, 47, p. 499, 1919.
June, July, 1919	August, 1919, 47, p. 580, 1919.
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September, 1919	October, 1919, 47, p. 748, 1919.
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